The WELDING JOURNAL

FEBRUARY 1954

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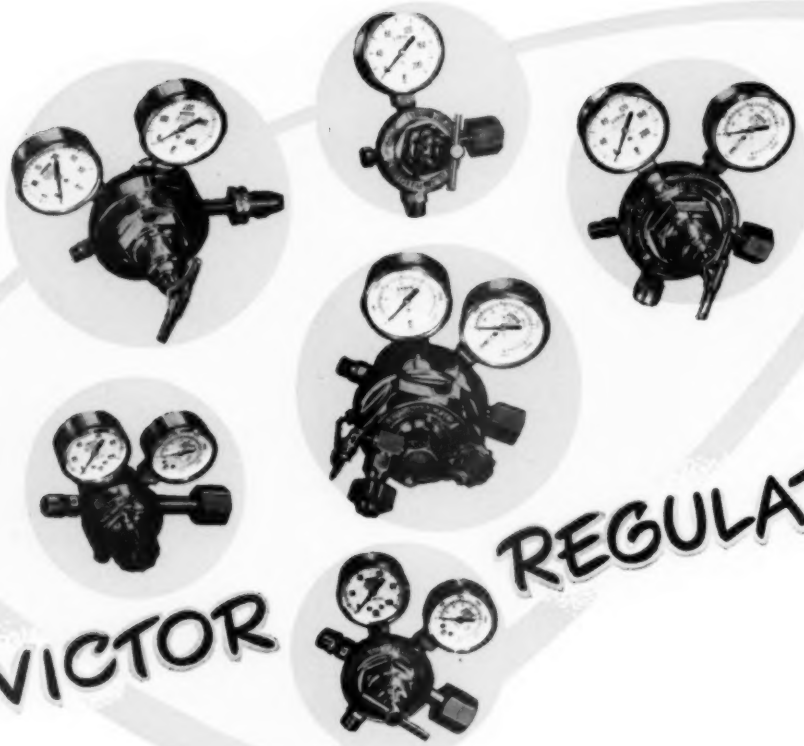

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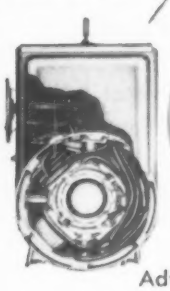

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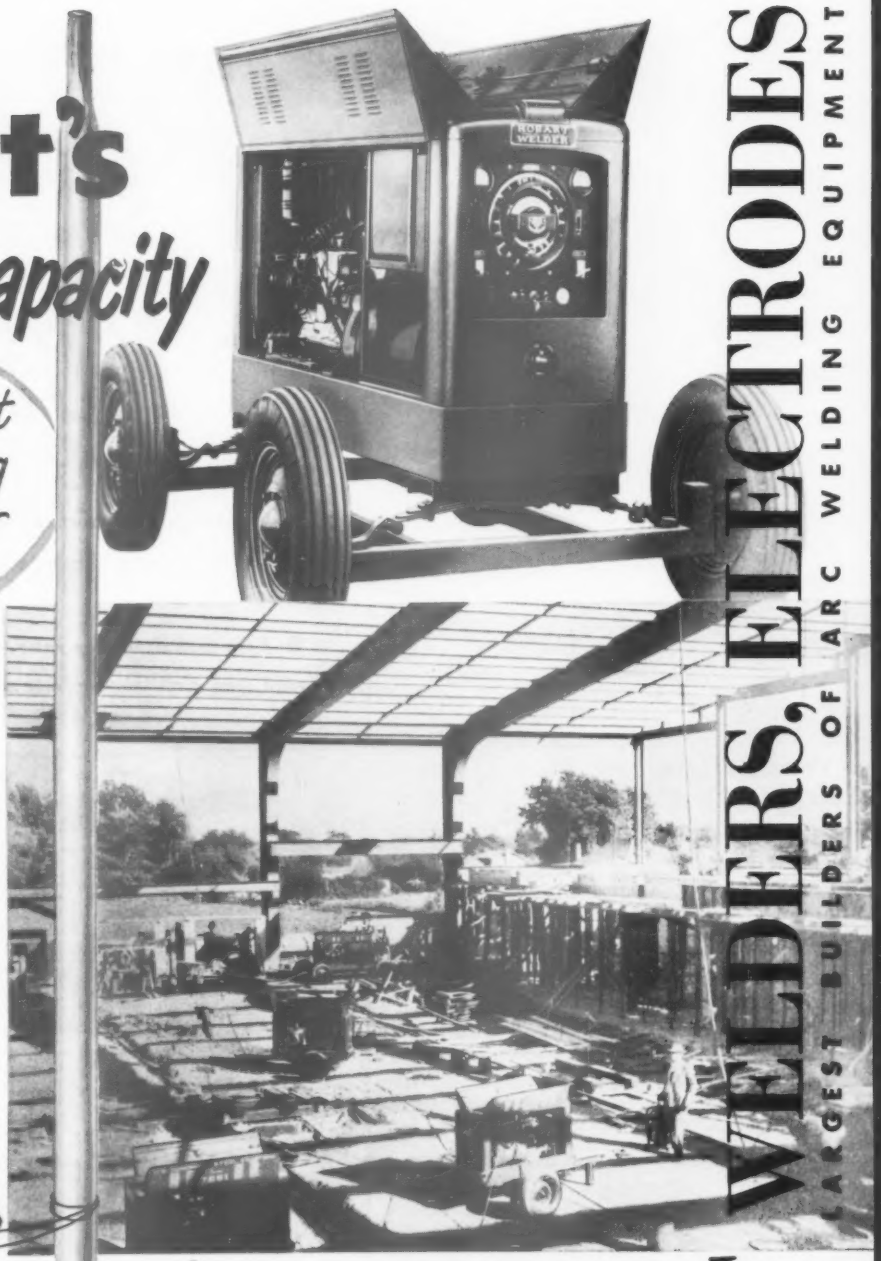

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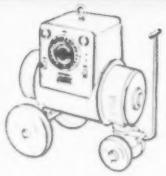

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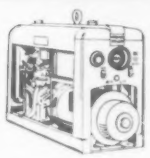

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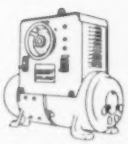

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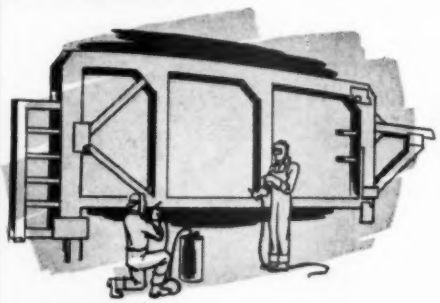

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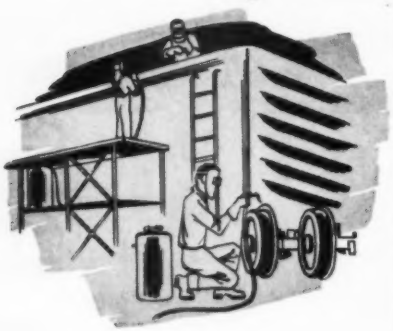

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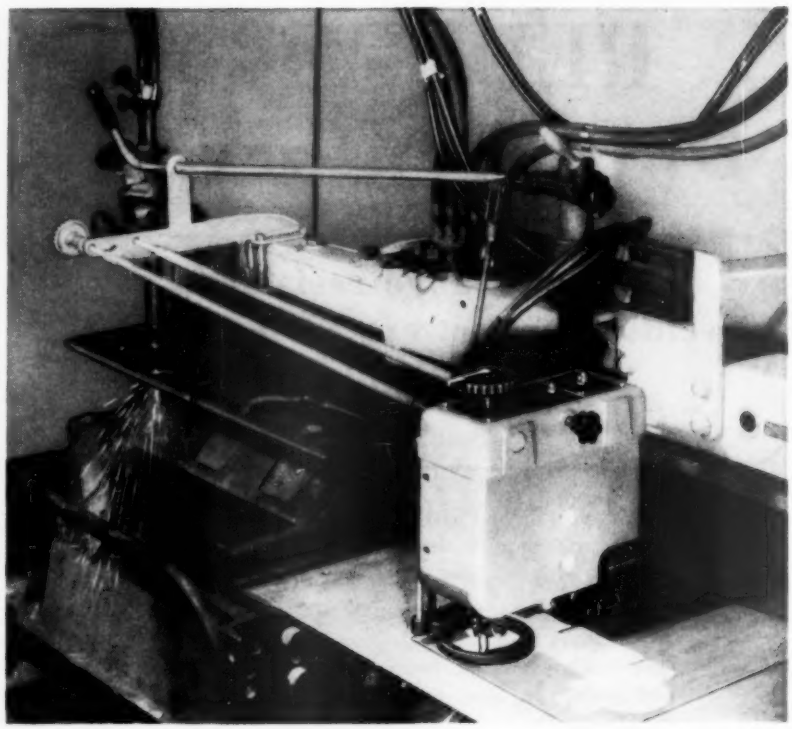

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The WELDING JOURNAL

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Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices 33 West 39th St., New York 18, N. Y. Subscriptions $6.00 per year in United States and possessions; foreign countries $7.50. Single copies, nonmembers $1.00; members 75 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton Pa., under the act of March 3, 1879. Copyright 1954, by the American Welding Society. The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided proper credit is given.

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The WELDING JOURNAL

volume 33 February 1954 number 2

Recent Applications of Welded Design to Industrial Building Framings

Interesting features and general framing arrangements of Navy stock buildings designed for prefabrication and special purpose buildings

by A. Amirikian and E. G. Odley

INTRODUCTION

INDUSTRIAL buildings present a fertile field for the introduction of improvements in design. The improvements may be in the form of reduction in materials of framing, simplification of fabrication and erection and, for certain types of buildings, easier packaging and reduction of shipping cubage. These are the desired objectives which the structural engineer is striving to achieve.

Reduction in the amount of steel necessary in a structure is of special importance in times of emergency when the supply is critical. At the present time, when there is no shortage, the need for savings in steel in a framing is dictated by the competition of other construction materials. In order to meet this competition successfully, it is necessary for the designer not only to select proper framing arrangements and choose economical structural components, but also to make optimum use of the potentialities of welding. In this task, for the economical realization of an adopted scheme, the cooperation of the fabricator becomes an important factor.

The Navy's Bureau of Yards and Docks, for many years a proponent of structural welding, has recently developed new designs of structures which are intended to meet the desired objectives. These buildings are of two types: (*a*) stock buildings designed for prefabrication in a modular arrangement; and (*b*) special-purpose buildings designed for a specific need at a given location.

A. Amirikian and E. G. Odley are with the Department of the Navy, Bureau of Yards and Docks, Washington 25, D. C.

Presented at the AWS Thirty-Fourth National Fall Meeting held in Cleveland, Ohio, week of Oct. 19–23, 1953.

Some of the interesting features, as well as the general framing arrangement, of these structures are described here.

PREFABRICATED INDUSTRIAL BUILDINGS

The need for the development and use of prefabricated buildings was brought about by war conditions. Their principal function was to provide a shelter or enclosure for a facility or operation in the shortest possible time.

Originally these buildings were intended for a limited service life, namely, duration of the emergency. Some were predicated on relatively thin sections utilizing light-gage steel, and others, where use was made of structural sections, were designed for low factors of safety. Presently, there are commercially available a number of prefabricated buildings of various types which are designed for longer service life and are accordingly of more substantial construction. However, the procurement of a proprietary type of a building by the Government creates a number of problems which are not always satisfactorily resolved. In order to obviate these difficulties, the Bureau undertook to design a series of structures adaptable for prefabrication. The substitution of these buildings for the proprietary types will greatly facilitate procurement, by making them generally available to all fabricators, and reduce the cost to the Government through competitive bids. In addition, the Bureau designs will incorporate certain desired design features and make optimum use of framing materials.

The first building of the planned series is a general-purpose building of 40 by 100 ft. The arrangement of the framing is shown in Fig. 1. In outline, the building has vertical walls 14 ft high at the eaves and a sloping roof rising to a height of 19 ft 6 in. at the ridge. The

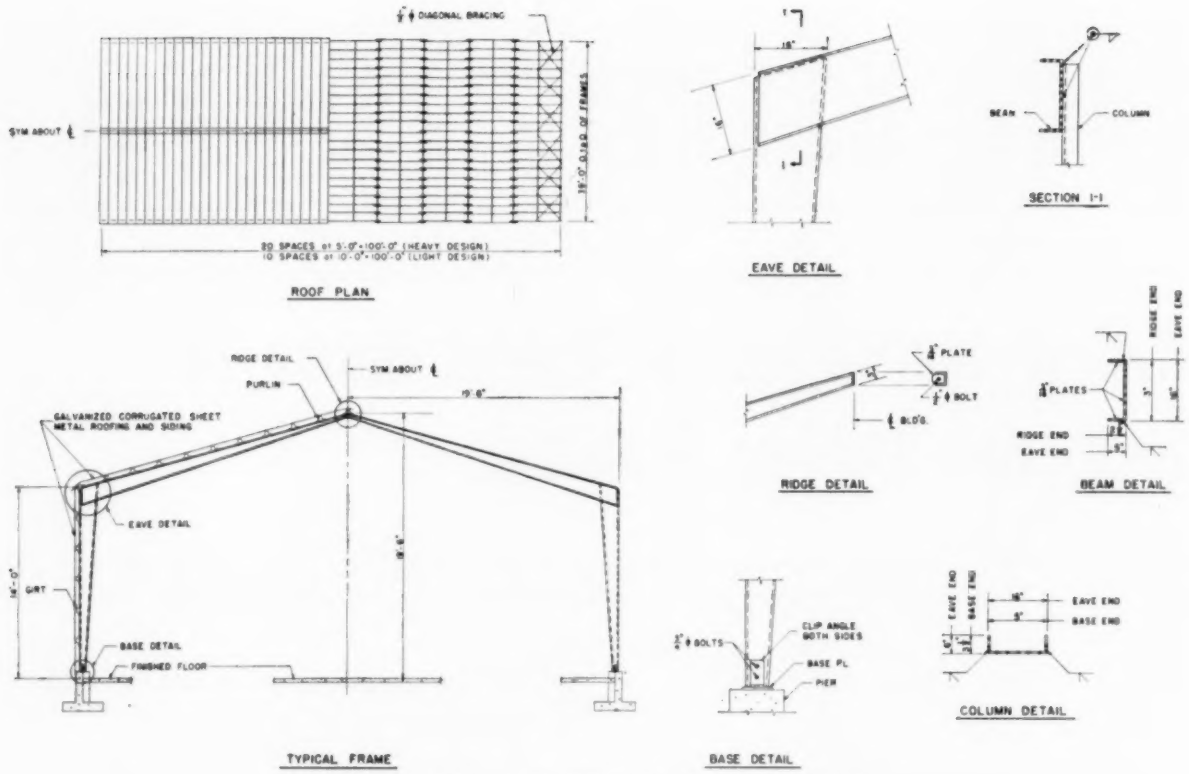

Fig. 1 Prefabricated building of wedge-beam framing

structure is designed for two conditions of loading, designated as light and heavy design. The loading of the former consists of 20 psf roof live load plus 70 mph wind load, and that of the latter 40 psf roof live load plus 70 mph wind load, or 150 mph wind load with no roof live load.

As will be noted, the main framing is featured by the use of wedge-shaped members. The principles and the advantages of this type of framing were discussed in a previous article of the JOURNAL.* In the light design the bents are spaced 10 ft on centers, and in the heavy design 5 ft. Both column and girder members are of tapered shape to facilitate assembly as well as packaging and shipment. Because of the tapered webs the members will nest one into another thus minimizing shipping space.

Welding details are shown in the figure. The corner joint, which is the most important connection, is normally welded. However, it may also be connected by bolting—if welding facilities are not available at the construction site. As yet, no final welding procedure has been established. Where quantity production is involved, there will be special equipment for fabrication including assembly jigs. Presently, the build-up of the members is predicated on placing the web in a horizontal position and welding the two flanges by a beveled edge detail.

The purlins and girts consist of hat-shaped elements of cold-formed light-gage sections, bolted and strapped to the frames. The spacing of the purlins and girts shown in the figure correspond to the heavy design. In the light design the spacing is about twice that shown. Continuity is obtained by overlapping the ends of the members at the frames. Since the sides or webs of these members are sloped, lapping is feasible. In the same way, packaging of these members is greatly simplified as they will nest into each other.

The roofing and siding consist of corrugated metal sheeting. Roofing sheets are 26 and 24 gages for the light and heavy designs, respectively, and the siding is 26 gage for 70 mph wind and 24 gage for 150 mph wind.

The total weight of all structural material, including the roofing and siding, given in pounds per square foot

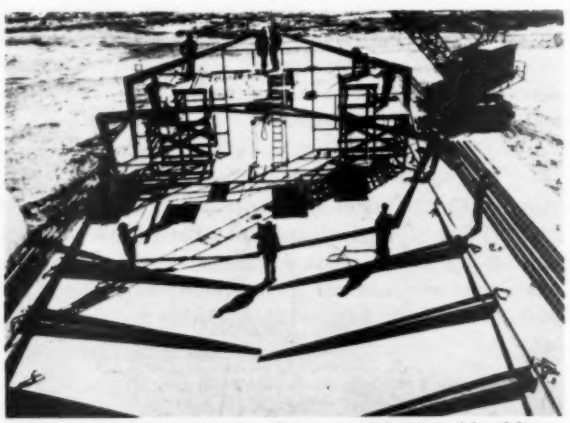

Fig. 2 Erection of wedge-beam prefabricated building

* Amirikian, A., "Future Developments in Welded Steel Buildings." THE WELDING JOURNAL, **27** (8), 593–599 (1948).

of floor area, is 6.67 for the light design and 9.19 for the heavy design. Studies and experiments on packaging of the light design by the Bureau indicated a minimum cubage of about 260 cu ft and a gross weight of about 28,000 lb.

In erection, the frames are assembled on the ground in the flat position, as illustrated in Fig. 2. After welding or bolting of the corner joint and bolting the ridge joint, each frame is lifted into position as a unit.

These structures have been tested under static and blast loading. In all the tests, the strength of the framing proved to be amply adequate.

GENERAL INDUSTRIAL BUILDINGS

Buildings used for shop and storage facilities constitute the major portion of structures comprising this group. These structures cover a wide variety of layouts in accordance with functional requirements. For this reason it is not feasible to standardize their framings for stockpiling—as in the case of prefabricated buildings. In general, it will be necessary to design and fabricate the framing for each project separately. However, the type of arrangement of framing can be standardized for adaptation to any given dimensional outline.

Two recent designs, prepared in the Bureau, are examples of this type of construction. They are intended for use as warehouses, but could serve equally as well for other purposes. In one of them use is made of wedge-beam framing, and in the other, conventionally arranged rigid framing. In both arrangements welding is utilized to a great extent.

Wedge-Beam Framing

The building with wedge-beam framing is shown in Fig. 3. It is a two-bay gable framing, with an over-all width of 106 ft, eave height of 14 ft 3 in. and ridge height of 20 ft $10^1/_2$ in. The frames are spaced 22 ft 6 in. on centers, instead of 20 ft as normally used in buildings of this type. This bent spacing, as well as the bay width, was obtained from a layout study to determine the most advantageous arrangement of pallets for fork-lift truck operation used in Navy warehouse work.

This building was designed for a roof live load of 40 psf and a 100 mph wind. Another building designed for a 20 psf roof load and 100 mph wind has a similar framing, differing only in the sizes of the elements composing the main frames. It is interesting to note that the wind loading creates alleviating flexural stresses in the greater part of the main frames, the favorable effect being due to the relatively large width-to-height ratio and the adopted gable height.

The principal details of the composition of the members and welding are shown in the illustration. It will be noted that, except for the center column, all

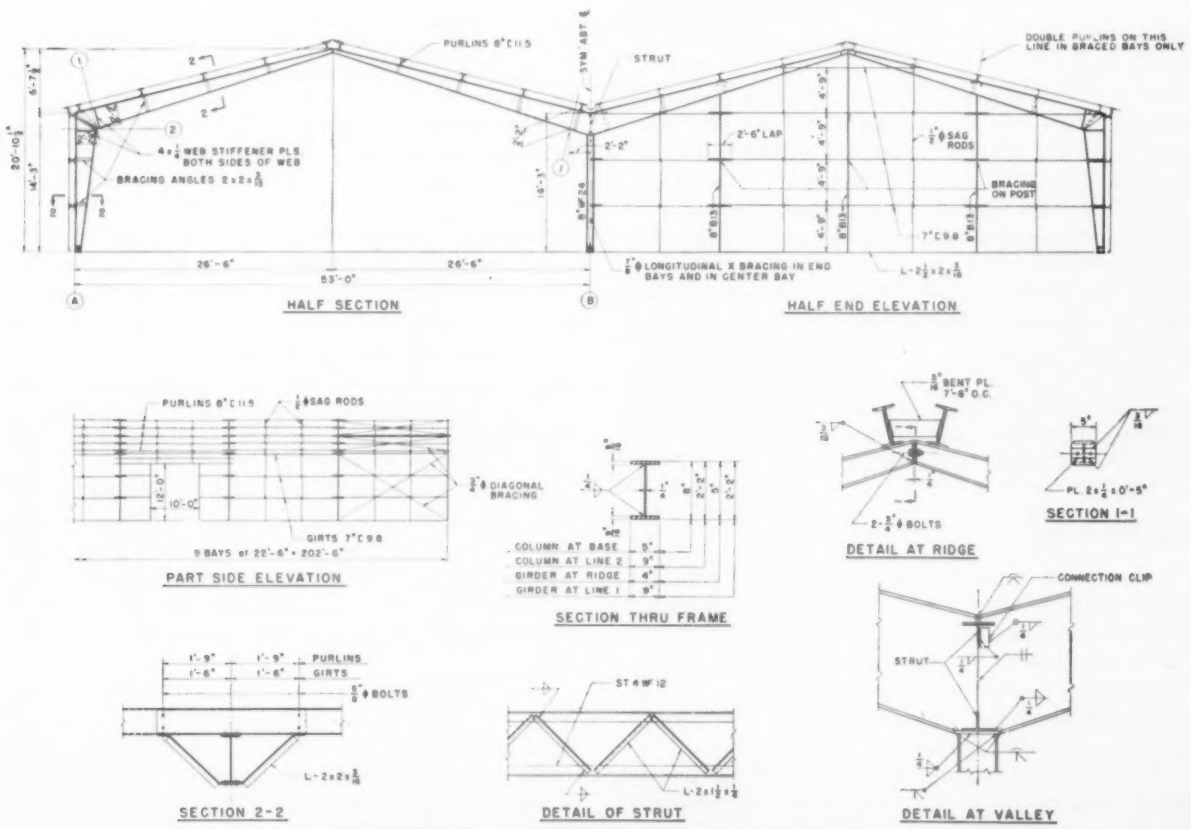

Fig. 3 Warehouse building of wedge-beam framing

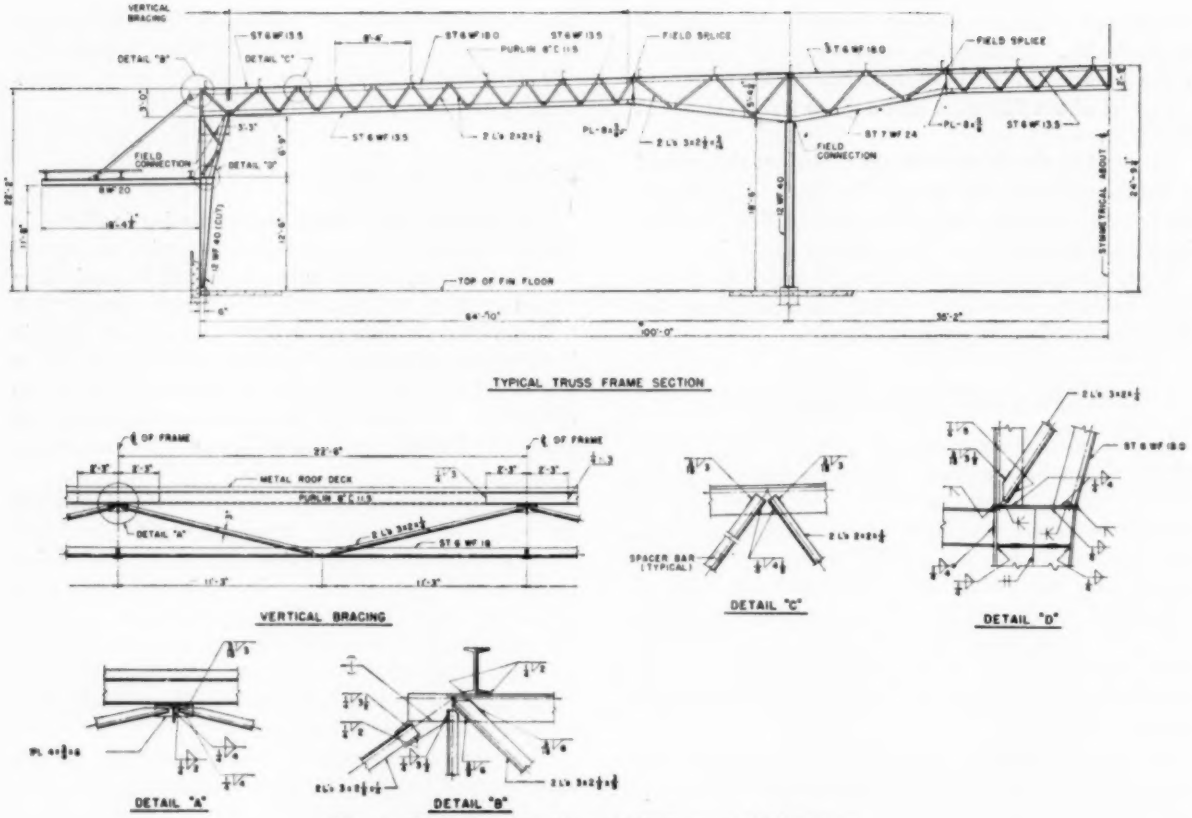

Fig. 4 Warehouse building of built-up rigid framing

members of the frames are composed of built-up I sections having tapering flanges and webs. At the ridge and the column bases the hinged condition assumed in the design is simulated by a bolted connection having a small moment carrying capacity. Purlins and girt consist of rolled channel sections placed back-to-back and lapped at the supports for full continuity and increased sections at these locations. A bracing strut, in the form of a latticed truss, ties the tops of the interior columns in the longitudinal direction. Corrugated protected metal is used for the siding and roofing.

The total weight of all structural material, including the roofing and siding, given in pounds per square foot of floor area is, 9.19 and 9.94 for the light and heavy designs, respectively.

Rigid Framing

Unlike most types of conventional rigid framing, where the bents consist essentially of an assembly of solid-web rolled sections, in the arrangement shown in Fig. 4 the frames are mainly of latticed members. This framing represents an attempt to reduce weight by taking advantage of continuity and the greater efficiency of built-up members.

The building is a standard Navy warehouse 200 by 600 ft, with 18-ft canopies. The bents are spaced 22 ft 6 in. on centers, and transversely comprise 3 bays; a center bay of 70 ft 4 in. and two side bays of 64 ft 10 in. each. The cross-sectional outline is established by the minimum clearance of 18 ft 6 in., the required depth of trusses at the supports and the minimum slope necessary for drainage. The building is about 23 ft high at the eaves and rises to a height of about 25 ft 7 in. at the center.

As in the case of the preceding building, the structure is designed for two conditions of loading, the framing shown in the illustration corresponding to the heavy loading of 40 psf. The design analysis was predicated on so-called 50% fixity at the bases of the columns and most unfavorable conditions of unsymmetrical canopy loading, in some parts of the building the canopy is omitted on one side as indicated in the roof framing plan in Fig. 5.

The truss portions of the main frames are of the Warren type utilizing T's for the chords and angles for the web members, the varying depths of truss corresponding roughly to the flexural moment pattern. The lower portions of the exterior frame legs are of wedge-beams formed by splitting and rewelding a 12-in. WF beam.

Since the bending stresses of the interior columns are relatively small, their design is governed primarily by axial stresses and elastic stability. While the use of rolled sections for these members involves some waste in framing material, no attempt was made to substitute built-up sections or wedge members here because the

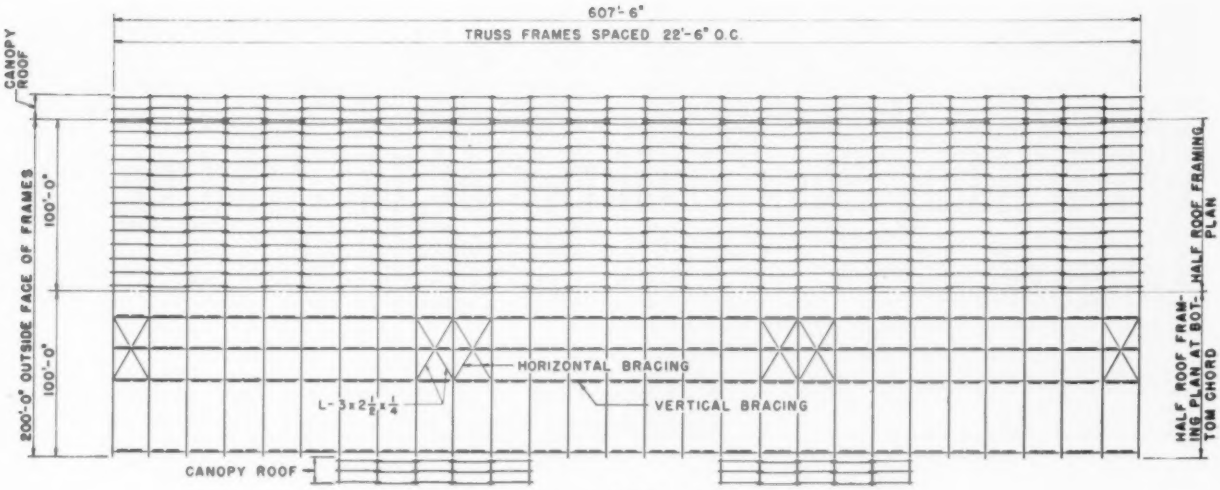

Fig. 5 Roof framing plan of rigid frame warehouse building

needed additional fabrication costs were estimated to be larger than the benefits obtainable from weight savings.

The secondary framing consists of eight vertical trusses and a system of horizontal diagonal bracing as shown in Fig. 5. The vertical trusses are composed of a T-section bottom chord and web members consisting of pairs of angles, connecting the center of the A to the top chords of the bents. The horizontal bracing consists of 3 x $2^1/_2$ x $^1/_4$ angles placed in the plane of the bottom chords of the vertical bracing trusses. Additional longitudinal rigidity is provided by the channel purlins which are of lapped arrangement and welded to the top chords of the frames.

Welding details are shown in Fig. 4. It will be noted that all bracing and web members of the trusses are joined to the chords by lapped connections in order to facilitate fitting, assembly and welding.

The roof consists of a 20-gage steel metal decking, supported on the purlins and covered with insulation and built-up roofing.

Exterior walls are of precast concrete panels, connected to the frames by means of welding insert plates which are cast in the panels.

The weight of all structural framing excluding the roof decking is 5.94 psf of floor area for the heavy design.

PRESENT AND FUTURE APPLICATIONS

As yet, none of the buildings has been extensively utilized. While the designs of these buildings are now available in the form of Bureau standards, no opportunities for widespread uses and mass production have been presented. From data obtained from limited applications available thus far, the full potential in the way of savings cannot be correctly gaged at this time. With greater experience, not only the needed dependable cost data will be compiled but also possible modifications in arrangement, as dictated by considerations of prefabrication and erection, will be introduced to further enhance the advantages of the framings.

In so far as the designs are concerned, the presented framings do not necessarily represent the limit of possible improvements. While they now reflect advanced thinking, additional savings in framing material may still be realized. This can be achieved through research. The use of wedge-shaped members has resulted in a number of new problems, some related to elastic stability and others to the most advantageous proportioning of sections. The satisfactory solution of these problems will unquestionably lead to further improvements. Toward this end, an extensive research project is now being initiated at Columbia University under the joint sponsorship of the Welding Research Council and the Bureau of Yards and Docks.

New Welding Shop Facilities at the Whiting Refinery

Description of a modern refinery welding shop and a description of methods and equipment in use

by Ray M. Kolb and Russell C. Wheeler

INTRODUCTION

SHORTLY after the formation of the Welding Department at the Whiting Refinery in 1914, headquarters were established in a small shop 30 ft wide by 50 ft long. Much of the early work in welding was seal welding riveted joints in vessels or screwed joints in pipe to prevent leakage. Since welding equipment was, in general, portable, the precedent was established to do a large portion of the welding work in the field rather than in the shop. A large yard back of the old shop was used to weld materials from areas where field welding could not be tolerated because of the fire hazard.

During World War II, a study was made of the economies that might result from the building of a large central welding shop. It was decided that considerable savings could be realized by doing as much work as possible in such a shop. Here the men would work under much more favorable conditions and should produce a generally higher quality of work. Welding Department supervisors would have to cover less ground in their everyday duties with the men working within the confines of the shop. Automatic welding equipment and better handling and working methods would give additional benefits. It was decided to build such a shop, and in the fall of 1949 it was completed and occupied by the Welding Department. This shop was built at a new location adjacent to the existing building housing the Boiler Shop, the Machine Shop and the Blacksmith Shop. This eliminated the need for moving men or materials from the old Welding Shop, which was over 1/4 mile away, on intercraft jobs.

It is the purpose of this paper to briefly describe the new Welding Shop and discuss the new methods and equipment that are in use.

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Presented on Oct. 23, 1953, at the National Fall Meeting, AWS, held in Cleveland, Ohio.

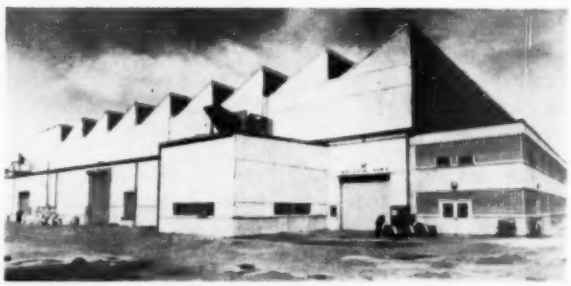

Figure 1

DESCRIPTION OF SHOP

Figure 1 shows an outside view of the new Welding Shop. The building is a steel structure with transite walls. A sawtooth monitor type roof was used which has windows in the vertical sections. These windows permit an appreciable amount of daylight to enter the shop and can be opened by motor operation to provide better ventilation in the summer months. To the right of the photograph, the portion of the building with glass brick walls houses the toolroom, the metallizing room and the welders' lunch room on the first floor. Foremen's offices and locker rooms, as well as locker rooms for welders, are located on the second floor. There are three motor-operated doors along the outside wall. The center door permits entrance of railroad cars, while the two outside doors are truck entrances. Most work is transported to and from the shop by motor truck, but frequently vessels or large pipe may be carried by flat cars and enter through the center door. The loading platform just to the right of the center door permits unloading of oxygen and acetylene bottles. In two separate rooms, they are connected to manifold systems which feed the entire shop. The projection from the building, with the blower on the roof, houses an annealing furnace. A view of this furnace from the inside of the shop is shown in Fig. 2. It measures 8 ft wide, 8 ft high by 30 ft deep. It is gas fired and is program controlled from the instrument panel shown to the right of the furnace.

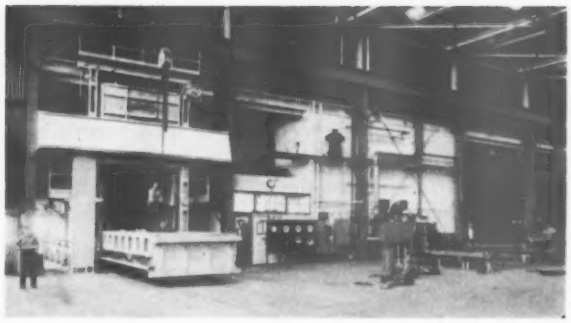

Figure 2

The welding shop is actually L-shaped, as it was built as an extension to a Mechanical Shops Building which already housed the Boiler, Blacksmith and Machine Shops. Figure 3 shows a 15-ton crane which services the main bay of the Welding Shop. The rear wall shown in this picture is common to the Welding Shop and the Boiler Shop. Two cranes service the Boiler Shop and they can enter the Welding Shop through motor-operated doors in the separating wall. The rails from the crane can be seen running down the center of the shop and along the wall to the left. Through the center of the shop numerous flexible ventilating hoses can be seen. Air is pulled through these 22 individual hoses by a large centrifugal blower having a capacity of 10,000 cfm. In addition, there are four smaller blowers having capacities of 2000 cfm each located around the walls of the shop which service 16 additional flexible hoses. The Machine Shop is located behind the wall to the left, and they were assigned additional areas back of the shielding, on the Welding Shop side of the wall. Along the center column in Fig. 3 can be seen two of the five jib cranes which serve the Welding Shop. These motor-driven hoists have a lifting capacity of 2 tons each and are movable on 10-ft long swinging booms.

Figure 4 shows a view down the main bay of the shop. This area is serviced by the 15-ton crane shown in Fig. 3. To the rear of this photo can be seen some heavy machine tools belonging to the Machine Shop,

Figure 3

Figure 4

but located here to permit servicing by the overhead crane. To the left of this picture can be seen the heavy cast-iron tables used for fitting up pipe. After fit-up, the pipe is moved to the central area of the shop, where welding can be seen in progress. The track to the right, in this photo, serves the car of the stress-relieving furnace. Looking along the ceiling, the overhead lighting and heating facilities can be seen. The work area available to the Welding Department amounts to about 21,500 sq ft.

IMPROVEMENT IN PIPE FIT-UP PROCEDURES

Most refinery piping assemblies are fabricated through the use of manufactured welding fittings such as tees, ells, crosses and flanges combined with lengths of straight pipe. Fit-up work of this nature consists of determining the proper lengths of straight pipe, cutting, beveling, properly aligning and tacking the parts together. Most oil-refinery piping material can be flame cut. However, if the piping material is of a variety not adapted to flame cutting, it is cut and beveled in the machine shop. Straight cutoffs used to be made by marking a line around the pipe, using the straight edge of a thin strap about 3 in. wide and long enough to wrap around the pipe about $1^1/_2$ times as a guide. This line was then followed with an oxy-acetylene torch, first making a straight cutoff and then beveling the pipe. This was slow and a machine-cutting method was desired.

To do this job, a pipe-cutting pantograph was purchased. It flame cuts the bevel on straight lengths of pipe as well as cutting some of the more complicated intersections. Figure 5 shows the machine cutting and beveling a length of 6-in. pipe. The pipe rests in drive rolls which rotate it at a variable cutting speed of 8 to 16 ipm under the cutting torch, which remains stationary. The bevel can be set at any desired angle, usually $37^1/_2$ deg is used in pipe work.

Figure 6A shows the type of bevel actually cut by this machine while Fig. 6B shows the type of preparation desired for pipe work. The land at the base of the

Figure 5

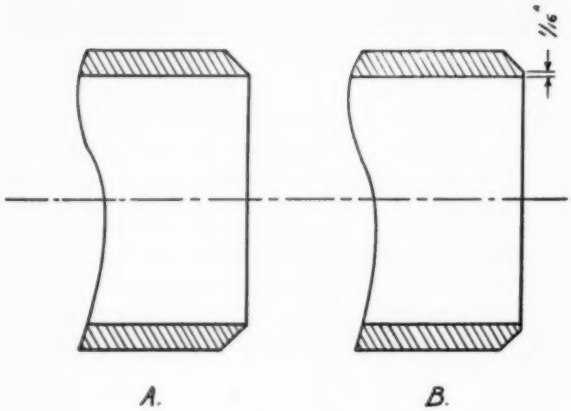

Figure 6

bevel aids in making a good root pass, which is very essential in high-quality pipe work. Attempts were made to flame cut this type of bevel and land by using two torches but the results were poor due to the smallness of the land and the eccentricity normally present between the inside and outside diameters of pipe. Figure 7 shows a device for grinding this land. It consists of an air-driven grinder mounted on a carriage which can be moved in and out by turning the handwheel at the rear. The entire rig is mounted on a portable hydraulic lift table having swivel casters and a floor lock.

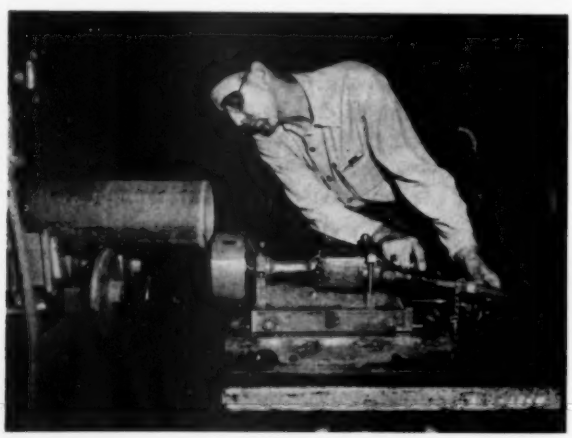

Figure 7

The table is pushed into position, elevated until the grinding wheel is properly aligned with the end of the pipe, and the floor lock actuated to prevent movement. The land is then ground by moving the grinding wheel inward with the pipe rotating in the pantograph. The reason for mounting the grinder toward one side of the table surface is that the table serves the additional function of supporting the free end cut from lengths of pipe. For this work the table top is elevated to within about $^1/_8$ in. of the free end of the pipe which then drops this small distance when severed. If the free length is appreciable, two of these tables are used. The pantograph has been used to cut the bevel pipe up to 24 in. in diameter.

In addition to piping assemblies composed of welding fittings it is often necessary to make intersections directly between the component pieces of piping. The pantograph can accurately and rapidly cut tee, lateral or miter joints. The tee and lateral connections cut by this machine can be either of the saddle or the insert type as shown in Fig. 8. In a saddle-type intersection the branch is shaped and beveled to rest on top of the header, the latter prepared with a straight-sided hole to conform with the inside diameter of the branch. For the insert-type intersection the header is cut and beveled to permit the branch to enter the opening. The branch is suitably shaped to conform to the inside diameter of the header.

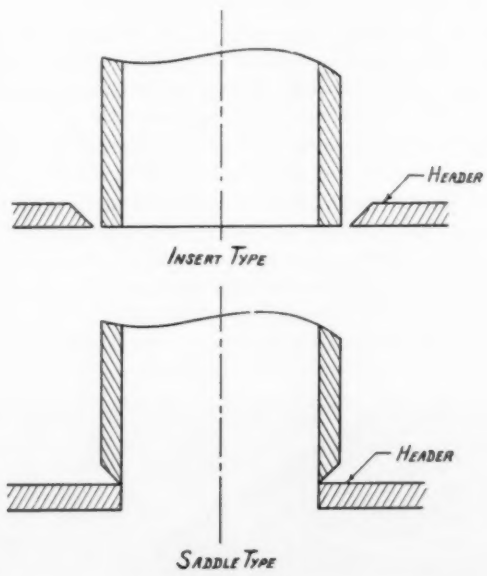

Figure 8

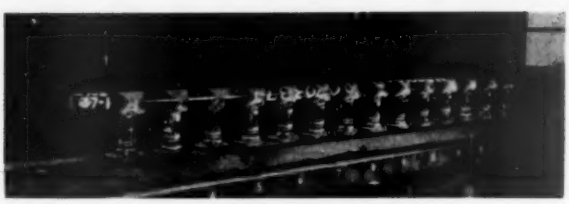

Figure 9

Figure 9 shows a recent piping assembly consisting of a header made of 4-in. standard pipe having fourteen 3-in. branches intersecting it on 10-in. centers. The bolt holes of the flanges were to straddle the centerline of the header. A saddle-type intersection was specified. Since there were 12 of the assemblies to be fabricated the job was studied from an economy standpoint and the procedure described below was used for fabrication.

Figure 10

Figure 10 shows one of the branch pieces being cut and beveled to fit on the header. A cam, shown in the right foreground of the picture, is synchronized to move the cutting torch in and out as the pipe rotates beneath it. After the shaped cut was made the pipe was moved forward the length of the branch and a straight cutoff was made. This forward movement is easily accomplished as the pipe can be raised on longitudinal rollers by means of a built-in hydraulic system and moved to the proper cutoff point. Some of the finished branch pieces can be seen on the table in the rear of Fig. 10.

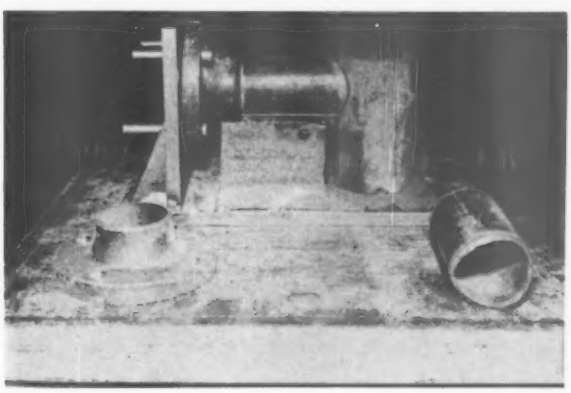

Figure 11

Figure 11 shows a fixture in which the branch and the flanges were tack welded together. The flange was attached to an angle plate by means of pins inserted in the bolt holes while the branch piece rested in a vee support with the shaped end properly aligned against a piece of 4-in. pipe properly positioned to simulate the header. The shape of the saddle-type welding groove can readily be seen in the photograph.

Figure 12

Figure 12 shows the holes being cut in the header. This is being done by the hole-cutting attachment which is part of the pantograph. In this operation the header remains stationary while the torch is rotated to cut the desired hole. A cam synchronized with the rotation of the torch raises or lowers it to follow the contour of the header. This cam can be seen adjacent to the support column in the top central portion of the picture. It raises and lowers the torch through the pivoted and counter-weighted arm with which it is in contact.

Assembly of the branches to the header was accomplished by fastening the branch flanges to a previously drilled I-beam. The header was then set on top of the properly centered branches and tack welded in place. This stage of the assembly is shown by Fig. 9. Following this, the saddle welds were made with the assembly still bolted to the I-beam to keep distortion to a minimum.

Figure 13 shows a piece of 24-in. pipe being cut off and beveled in the pantograph machine. The far end of this pipe length has previously been prepared for a 45-deg lateral saddle-type intersection with a 36-in. OD pipe. The cam to make this intersection was laid out, using simple principles of analytic geometry, and the resulting intersection fitted perfectly. To change the machine from one type of cut to another merely involves installing a different cam and another set of change gears. This operation can be done in a few seconds. The manufacturer of this machine provides cams for practically every type of intersection, and it is unusual for us to design cams except in very special cases similar to the one in Fig. 13. Prior to the purchase of this machine, intersections were marked on the pipe by templates, by geometric methods or by special

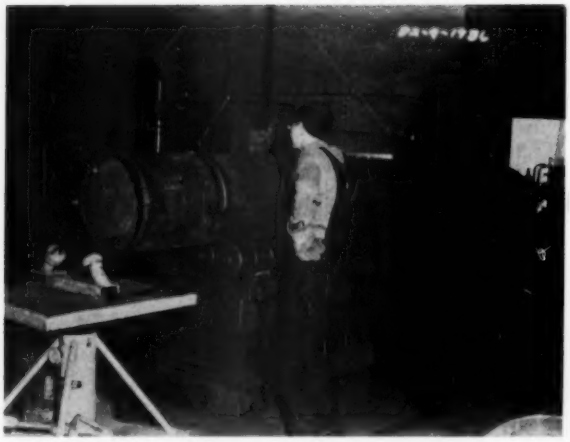

Figure 13

tools. The burner then cut the pipe, following the line to the best of his ability and estimating the proper angle by eye. This operation required considerable skill, and the completed product of an expert burner still lacked the accuracy and smooth cut obtained from the machine in much less time.

Two-dimensional piping assemblies are fitted up by resting the pipe in roller supports similar to the one shown in the foreground of Fig. 13. These supports are usually placed on heavy cast-iron fit-up tables, but the use of hydraulic lift tables for fit-up is increasing in popularity.

Figure 14 shows how a shop elevating table can be used to advantage in three-dimensional fit-up work. Considerable work is in progress to further mechanize fit-up operations, but at the present time we rely primarily upon the skill of our men for proper alignment.

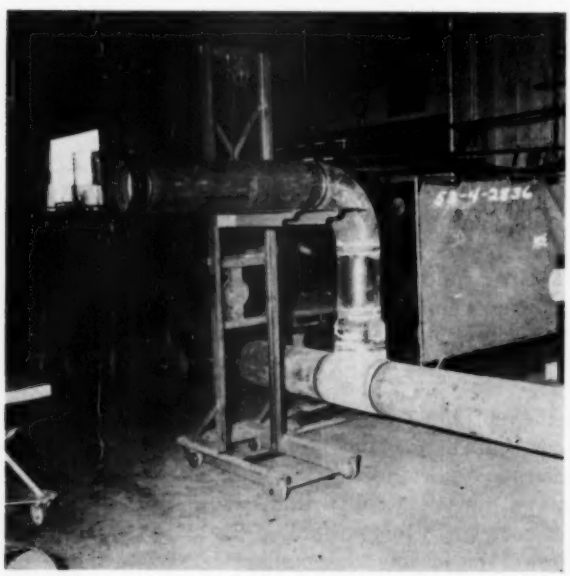

Figure 14

AUTOMATIC SUBMERGED ARC WELDING

Automatic submerged arc welding has been used extensively in our shop operations. In this process the welding takes place below a blanket of granular flux and is limited to jobs where the flux will remain in place due to gravity alone or where suitable dams can be devised to hold it in place. Our work has been limited to roll welds on pipe and small vessels and to straight-line seam welds made in the flat position.

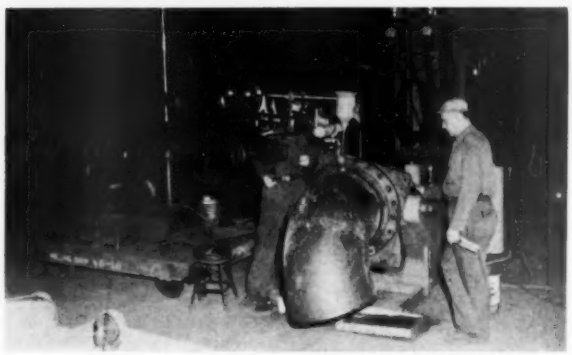

Figure 15

Figure 15 shows the submerged-arc welding rig joining a 24-in. flange to an elbow. The assembly is being rotated below the stationary submerged-arc welding head by means of a variable speed positioner capable of imparting the proper surface speed for welding. The submerged-arc welding head is mounted on a boom-and-column type positioner. The boom has a motorized up-and-down movement, but the carriage on which the welding head is mounted is traversed in and out by hand. The boom can be rotated through 360 deg on the column. The entire boom-and-column rig is mounted on a mobile base equipped with knuckle-type steering, similar to that used on an automobile, and rubber-tired roller-bearing casters. This mobile base, which measures 6 x 6 ft, was sized to prevent any possible overturning. Two men can easily pull this equipment to any desired location in the shop. The boom projects out 8 ft from the center of the column and can be raised upward 9 ft above the floor. For special applications a spool piece has been installed between the

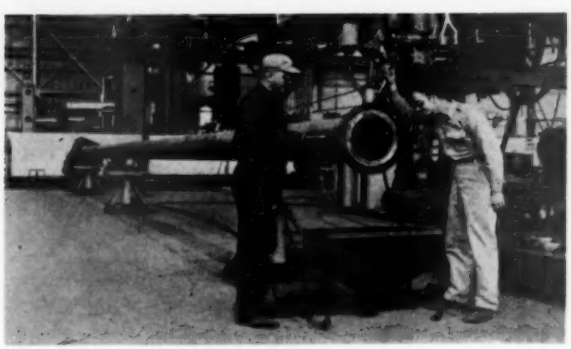

Figure 16

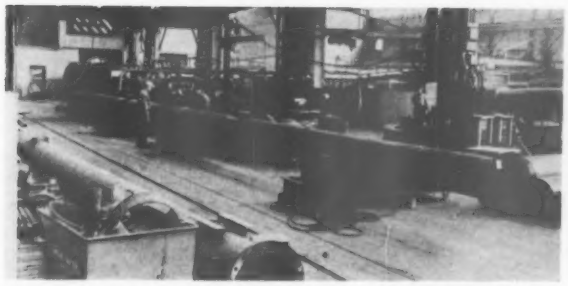

Figure 17

column base and the mobile base to raise the boom 12 ft above the floor. The welding head is energized by two 500-amp a-c welding transformers. For work requiring less than 500 amp only one machine is used, but for heavier work the two transformers are paralleled to give up to 1000 amp of welding current.

Figure 16 shows a long length of pipe being automatically welded by submerged arc. In this case there were two flange welds plus a butt weld in the center of the assembly to be made. The pipe is supported in rubber-tired rolls mounted on hydraulic-lift tables. This arrangement permits the rapid leveling and aligning of the pipe with the positioner which is used to rotate the pipe. The flange weld closest to the positioner face was made first, then the submerged arc rig was pulled to the center of the assembly to make the center weld, and in the position shown the final flange weld is being made. In pipe welding, the root pass is made manually and the weld is completed by the submerged-arc process. It has been found that it is practical and economical to weld pipe 6 in. and larger by the submerged-arc process. For smaller pipe the curvature is too great to retain the flux properly and a poor weld results.

Ball-type conveyor rollers were used to support the pipe in our earlier submerged arc-welding work. Considerable difficulty was encountered with irregular turning with these ball supports because much of the pipe we use is rusty from outdoor storage. The rubber-tired ball-bearing supports we are currently using are 10 in. in diameter and 3 in. wide. Rolling the pipe in them produces smooth rolling, ideal for welding. Lengths of pipe, similar to the one shown in Fig. 16, up to 100 ft long have been welded with his rig.

Figure 18

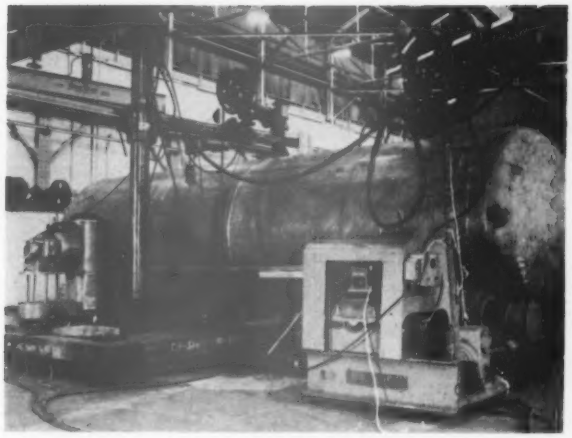

Figure 19

Figure 17 shows two 40-ft long lengths of 20-in. pipe being joined together by a central butt weld. There were four 80-ft lengths of this 20-in. pipe and four 80-ft lengths of 36-in. pipe to be fabricated in this manner. The pipe was rested in one set of power-turning rolls and three sets of idler rolls for this operation. Fit-up was accomplished by aligning the four sets of rolls and then setting the 40-ft lengths of pipe in them. The root pass was put in by hand and the welds finished automatically. The 36-in. pipe is the largest we have welded to date. While powered-turning rolls have considerable application they must be very accurately aligned to prevent longitudinal creeping as the pipe rotates. For this reason we prefer to use the type of rotating arrangement shown in Fig. 16 for pipe work.

Figure 18 shows a small vessel being rotated by a faceplate type positioner for welding. It is supported on rubber-tired rolls blocked up from the floor to match the centerline of the positioner face. Figure 19 shows a girth weld being made on a larger vessel which is being turned by the power rolls.

Figure 20 shows a longitudinal seam weld being made in a small vessel. Here the submerged-arc welding head is mounted on a variable-speed carriage which travels on a straight track. The ends of the track are

Figure 20

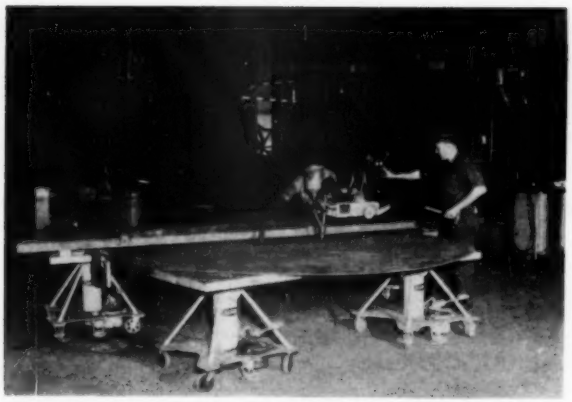

Figure 21

resting on hydraulic elevating tables which perm't height adjustment. Figure 21 is a similar setup for making seam welds in a tank bottom.

It is our feeling that submerged-arc welding has a bright future in our shops. High-quality welds can be produced rapidly with far less operator skill required than to make manual welds. We are currently constructing a smaller mobile rig to be used exclusively for pipe work. This rig will be considerably easier to move around the shop.

METALLIZING

A room 18 x 22 ft was built in the new shop for metallizing. The room was kept small to obtain better ventilation. Figure 22 shows the metallizing installation building up a large stainless-steel compressor rod with Type 420 stainless steel. The 2000-cfm ventilating fan, which pulls air through the hooded arrangement into which the metallizing gun is spraying, can be seen in the upper right-hand corner of the photograph. This hood moves with the carriage of the lathe and is connected with the blower by means of a telescoping duct arrangement. The lathe used has a 22-in. swing and a 10-ft bed. It is an old machine tool previously used by our machine shop. The sound absorbent lining around the upper half of the room and ceiling was installed to cut

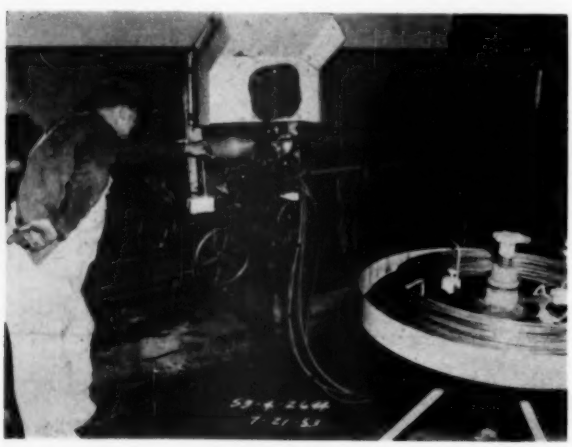

Figure 22

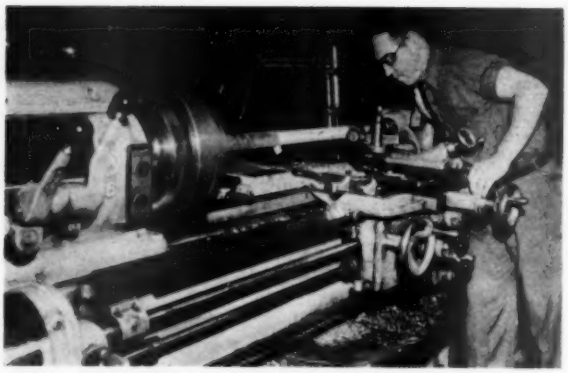

Figure 23

down on reflected noise. The shelter above the metallizing gun was intended to function similar to a shop phone booth. When the operator stands with his head in this shelter the noise is less apparent.

In our shops, the machinists prepare the work for the welders to metallize. Surface preparation is the most important factor in metallizing work and it receives extreme care. Our procedure is to cut a sharp 60-deg vee thread about 25 threads per inch and then to roughen it with a special roller-type tool. Figure 23 shows this tool roughening a shaft. It is desirable to metallize as soon as possible after the surface is prepared in order to prevent any possible contamination or oxidation. However, because our work must be transported from the machine shop to the welding shop, there is always some delay. As protection against exposure we have followed the procedure of wrapping the prepared surface in heavy brown paper and sealing it with tape as soon as the machinist finishes his work. The practice has been used for several years, on hundreds of parts, without any apparent loss of bond strength. Figure 24 shows a shaft wrapped ready to go to the welding shop.

It is our practice to use a light spray coat of molybdenum on top of the roughened surface, as this produces a better bond. Most of our work is in building up shafts, rods or plungers from such equipment as pumps, turbines, compressors, valves and motors. A favorite material for build-up has been Type 420 stainless steel, which produces a hard wear-resistant surface which can be ground to an excellent surface finish.

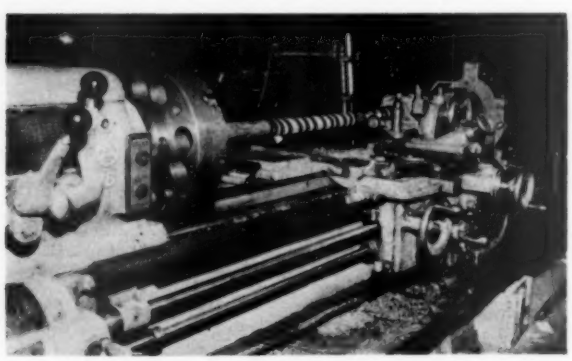

Figure 24

Fabrication of a Zirconium-Lined Reaction Vessel

Successful welding of zirconium is usually accomplished by the inert-gas-shielded process with additional protection by inert gas on the underside of the weld

by O. G. Paasche and A. J. Killin

INTRODUCTION

WITH the development of the Kroll process for production of ductile zirconium by the U. S. Bureau of Mines the metal has become available in relatively large quantities for use as a structural material. The Bureau station at Albany, Ore., has become a large-scale producer of the metal and is continuing research on improved methods of production, fabrication and use of zirconium.

During researches on process improvements it became necessary to construct a reaction vessel, which, because of the highly corrosive nature of the reaction products, necessitated the use of a corrosion-resistant lining. Partly because of its excellent corrosion resistance and partly because of the availability of the metal to the Bureau station, zirconium was selected as the lining material. All the zirconium used in the fabrication of the vessel was produced, melted and rolled to sheet at the Bureau plant.

Ductile zirconium has many properties of special interest. It has adequate strength and ductility for structural use and fabrication by the usual methods, and its resistance to corrosive action by common acids, bases and salts is excellent, exceeding that of stainless steels in many cases. It is readily attacked by hydrofluoric acid but is resistant to other agents as shown in Table 1.

While zirconium has adequate ductility to be formed by bending, its fabrication by welding presents some difficulties. The metal absorbs gases readily from the atmosphere when heated. The atmospheric gases, especially oxygen and nitrogen, cause a rapid increase in hardness with a consequent loss in ductility when present in even small amounts. Any joints formed by welding without adequate protection are, therefore, extremely brittle and break at low loads. The corrosion resistance is also affected to some extent.

Table 1—Effect of Common Agents on Corrosion of Stainless Steel (18-8 Type) and Zirconium

Agent	*Concentrations*	*Corrosion rate, ipy* — *Stainless*	*Zirconium*
Atmosphere		No attack	No attack
Salt spray	20%	Pits	No attack
HCl	10%	0.065	0.0002*
H_2SO_4	10%	0.079	0.0007*
HNO_3	Conc.	0.018	0.00005*
HF	All	Rapid attack	Rapid attack
NaOH	50%	Nil (10%)	0.00017*
H_3PO_4	10%	Nil†	0.00005*
$FeCl_3$	10%	Pits	0.00005
Citric acid	10%	Nil	0.00002*
NaF	10%	.....	0.0003*

* Hot.
† Nil: Less than 0.000.

The welding of zirconium is, therefore, usually accomplished by the inert-gas-shielded arc process with additional protection by inert gas on the underside of the weld. Experience with welding of zirconium has also shown that the use of metal backing plates securely clamped to the underside of the weld aids greatly in keeping contamination to a minimum, because the welding heat is extracted from the weld and heat-affected zones much more rapidly. The reduction in heat aids in reducing the time that the metal is at the elevated temperature where gases are absorbed most rapidly. Figure 1 shows a sketch of a typical welding setup. Every effort should be made to keep the protecting gases in contact with the metal as long as possible. Although it was not used in this project, a cover plate or follower on the arc torch is recommended as an aid in keeping the gases in contact with the metal until it is cooled to a temperature such that gases are not absorbed readily. The under side is also protected as shown by a jet of inert gas. A good check on the adequacy of protection is to note the color of the oxide coating. If this coating is colorless, adequate protection has been maintained.

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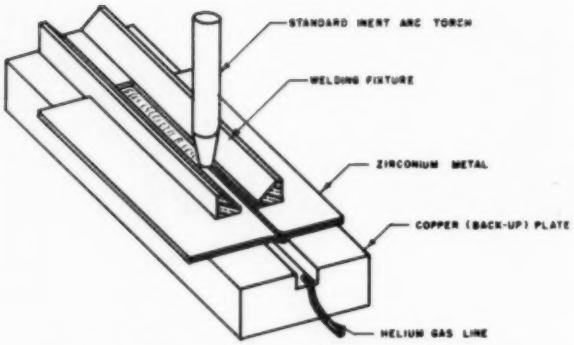

Fig. 1 Typical setup for welding zirconium sheet

No welding rods have yet been developed for zirconium. If used, they should be of the same composition as the zirconium being welded. It has been found that the best joints are those made by using the base metal to fill the weld. In practice the sheet is crimped at an angle of 20 deg and the two pieces to be welded placed together so that they overlap approximately $^1/_8$ in. This lap is then welded together using the inert-gas-shielded arc.

EQUIPMENT AND TECHNIQUES

The equipment used in the fabrication of the vessel lining, in addition to the usual machine and sheet-metal shop equipment, consisted of welding equipment assembled especially for the welding of zirconium. This included a General Electric 4200 series welding generator with an extra low amperage tap. The electrode holder, in which a $^1/_{16}$-in. thoriated tungsten rod was used, was an Airco water-cooled inert-arc torch with a ceramic gaseous diffusion cup. In addition a Muhlenbach amperage control, which is a rheostat with foot control, was employed. A General Electric flow control that could be adjusted for either manual or automatic control on the water and gas lines was also used.

Whenever possible, lap joints were used, and these were made in a fixture similar to that shown in Fig. 1. Helium gas was fed through a pipe into the groove in the backing plate. Helium was selected for this purpose, because, being lighter than air, it would tend to rise and cover the under surface. A dam on the back end of this groove prevented the helium from passing on through, and it was forced to escape between the crimped sheets.

Argon gas was used in the electrode holder, since this gas, being heavier than air, tends to lay down on the weld, thus protecting it for a longer period of time than if a lighter gas were used.

Prior to the actual welding of the vessel itself, several test welds were made using the techniques

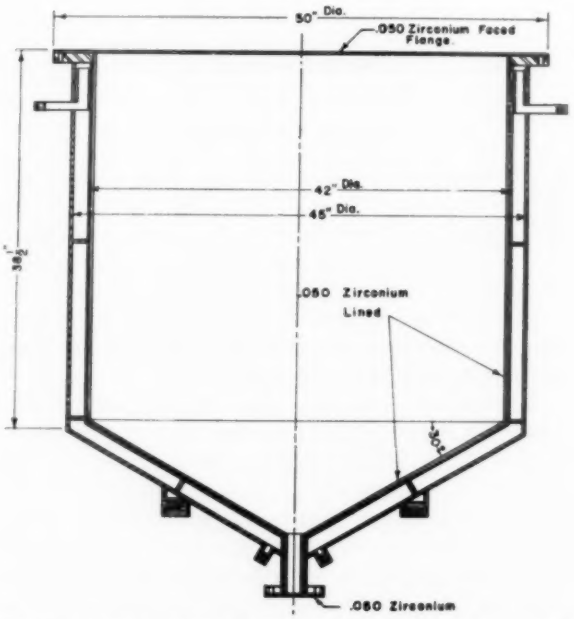

Fig. 2 Cross section of zirconium-lined reaction vessel

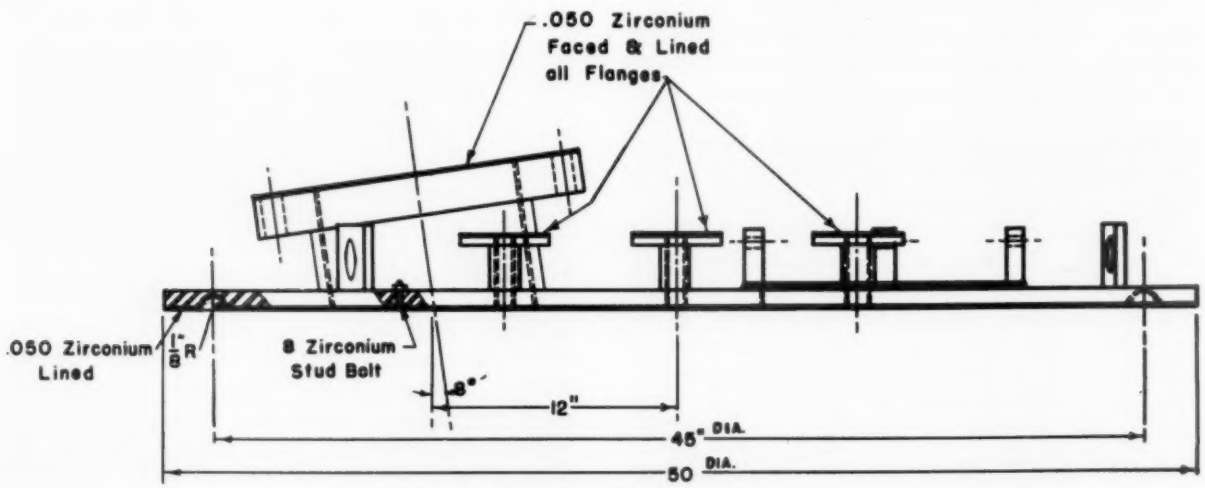

Fig. 3 Cover of reaction vessel

described. All tests showed weld strengths in excess of the parent metal and showed only a slight discoloration of the weld and heat-affected zones.

While welds in flat sheets are capable of being welded in the manner described above, corner welds are not so readily adaptable to a fixture of this kind. In this case it was necessary to use a filler rod of the same material as that being welded. Wires $^{3}/_{32}$ in. in diameter were placed in the junction of the two sheets and welded using the same welding torch.

In all cases a d-c current with straight polarity was used with a welding current of 100 amp at 13 v. No data were taken on the flow of water and gas, and no attempt was made to measure the rate of travel, since hand welding was used throughout, but it is estimated that zirconium welds readily at rates generally used for stainless steels.

FABRICATION OF THE VESSEL

A drawing of the zirconium-lined reaction vessel is shown in Fig. 2, while the cover of the vessel is shown in Fig. 3. As indicated in these drawings, all parts in contact with the reactants or their vapors are lined with zirconium. This includes the cover flange on the vessel itself, outlet pipe and flange as well as the entire under side of the cover, inlet pipes, manhole and stud bolts. The lining was 0.050-in. thick zirconium sheet. The metal was made in the plant of the Bureau of Mines and was melted and rolled to sheet in the Bureau shops. Since the capacity of the equipment was limited, the sheet had to be made in relatively small pieces, which necessitated more welding than would ordinarily have been required.

The cylindrical wall of the lining was made by welding together several sheets in a fixture as shown in Fig. 4. The conical bottom was also welded in this fixture. In this case, however, triangular sections were welded together until two halves of the cone had been formed. These two halves were then placed in the fixture shown in Fig. 5 and clamped in place by means of the nut and screw shown in the upper part of the photograph. A rubber gasket under the washer served to prevent the escape of helium gas, which was led into the space between the conical bottom and the table top by means of the tube shown. An annular ring kept the large diameter of the cone in proper dimensions. Again argon gas was used in the electrode holder to protect the upper surface of the weld.

After the cylindrical and conical sections had been fabricated, they were placed in position in the steel shell of the vessel, and welding thereafter was done in place. In order to protect the under surface of these welds, it was necessary to feed inert gas to the space between the lining and the shell. This was accomplished by making a hole in the steel shell at a point just below the upper flange, and a pipe inserted into this hole carried the protective gas into the space. It was necessary to seal off the space by placing a rubber gasket in the groove between the lining and the shell at the upper flange and also at the outlet pipe at the bottom. All welds in the vessel were made by using a filler rod in the manner described previously.

Next the flange lining at the top of the vessel was welded to the cylindrical lining. The gasket seal was moved to the outer edge of the flange, the under side of the weld being protected as above by the helium gas fed in through the same inlet tube.

A tube of proper diameter was made of zirconium

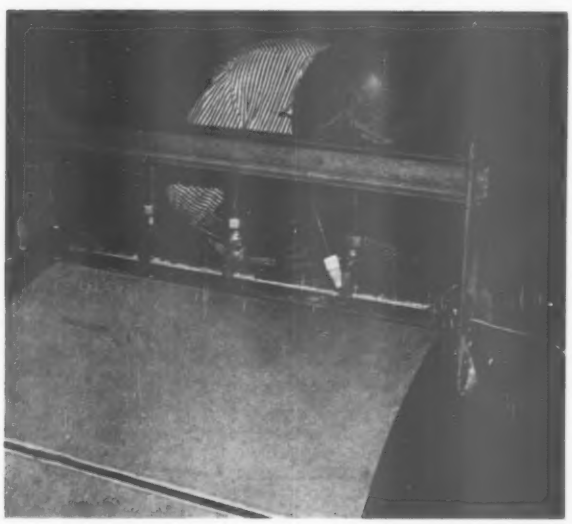

Fig. 4 Fixture for welding flat sheets of zirconium metal

Fig. 5 Fixture for welding conical bottom of reaction vessel

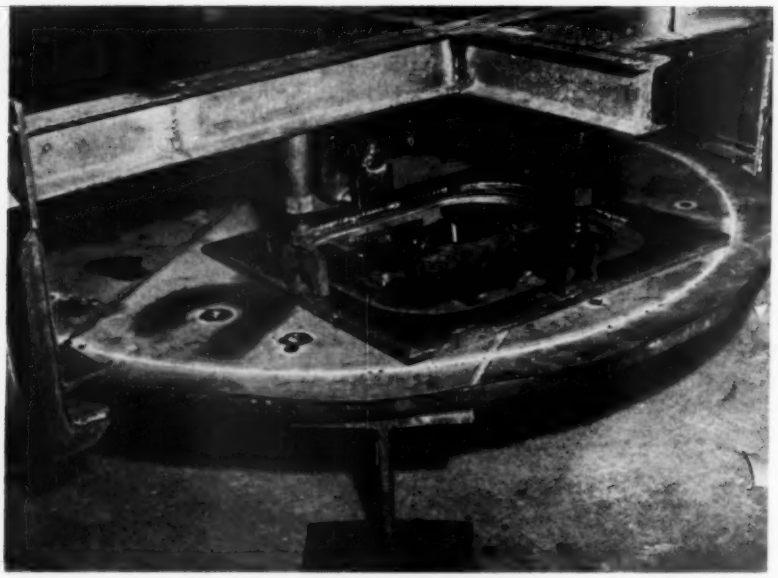

Fig. 6. Fixture for welding manhole cover

sheet in the same manner as described for the cylindrical section and this, too, welded in place. After welding the flange on this tube, it was discovered that sufficient shrinkage had occurred to break the flange off again as the weld cooled. Another tube was made approximately $^{3}/_{32}$ in. longer than the outlet section of the vessel. After welding this tube and flange in place, the tube shrank sufficiently to bring the flange lining in close contact with the flange itself. From this and similar experiences it is estimated that the shrinkage of zirconium during welding is about three times that of mild steel.

The lining of the vessel cover was next fabricated using zirconium sheet as before. This sheet was also formed from smaller sections welded in the same manner as the cylindrical section. A circular section of this formed sheet was cut out as also were holes for manhole and inlet pipe. This sheet was then clamped and sealed around the outer edge to the cover plate. The linings for the inlet pipe and the manhole were then welded in place in much the same manner as described for the outlet pipe on the vessel itself. Since the manhole was not circular in cross section, the welding of it required a special jig as shown in Fig. 6.

Recessed grooves in the flanges at the top of the vessel, the manhole cover, and the outer edge of the main cover were necessary to accommodate an "O" ring seal. These grooves were made by heating the lining material with a torch until it glowed red (about 1000° F) and indenting the lining with a formed tool and hammer.

CONCLUSIONS AND RECOMMENDATIONS

The experiences in handling of zirconium during fabrication and welding gained from this work have already proved valuable in improving the techniques used in fabrication of other equipment at the Bureau plant. The vessel has now been installed, and no defects or difficulties which can be attributed to the welding of the zirconium lining have been experienced. No sign of corrosion by the reactants in the vessel has been evidenced. Since all the welds were of good appearance with little oxide formation noted, this result was anticipated.

As a result of this work, it has been shown that adequate protection of both the under and face sides of the weld must be provided in order to retain the ductility of the metal. This necessitates the use of special setups, some of which are described. In addition provision must be made for the shrinkage which occurs during welding. It is estimated that this shrinkage is about three times that which occurs in mild steel.

While the welds made during fabrication of this vessel are satisfactory, it is felt that some improvements in technique can be made. While the fixture shown in Fig. 1 was satisfactory, it is believed that improved welds can be obtained, if provision is made for water cooling in the copper backing plate and the clamping bars. This would remove heat at a still faster rate allowing even less time for absorption of gases. In addition some kind of cover plate or tail on the welding torch is desirable in order to provide a cover of argon gas for a longer period of time. It has also been suggested that a mixture of argon and helium gases might provide even better cover than gases used separately.

ACKNOWLEDGMENTS

The authors wish to acknowledge the help of many members of the staff of the Bureau of Mines, without whose assistance the fabrication of the reaction vessel would have been impossible. Special acknowledgment is due K. E. Royer who conceived the design of the reaction vessel; W. A. Phillips for the design and drafting; J. H. McClain, under whose direction the vessel was designed, and E. T. Hayes for his continued interest in the project as well as his criticism of the manuscript.

Silver and Gold for Brazing Electronic Components

Composition and solidus and liquidus temperatures of silver- and gold-brazing alloys and how they are used in electronic applications

by A. W. Swift and R. J. Metzler

Abstract

This paper gives a discussion of silver and gold alloys used for brazing various components employed in the electronic industry. A listing of the alloys discussed, showing their composition and solidus and liquidus temperatures, is included. Most of the known applications of these precious metal brazing alloys are covered by showing why, where and how they are employed. The use of sequential brazing, where subassemblies brazed in the higher temperature range are joined in final assembly with a lower temperature range alloy, is also treated. Where possible, illustrations and tables are used for clarity.

It is shown, in this paper, that there are many precious metal-brazing alloys which have merit for electronic applications. Among these there are some which are supplementary and complementary to others which are better known and are in more common use.

INTRODUCTION

THE growth of the electronics industry both in volume and in technical complexity has created many new demands for brazing alloys and brazing techniques.

While a large portion of current electronics production still is used for military items, these are not the only applications. Some of the better known commercial electronic developments which employ brazing are induction heating units, dielectric heaters, color-television equipment, closed-circuit TV units, photo-electric printing and engraving machines, two-way radios and radio telephones, microwave stations for transcontinental telephone and television transmissions, navigation instruments and bowling-alley pin spotters and foul detectors.

Many electronic components require only the usual characteristics of silver brazed joints: high strength, leak tightness, good appearance and economy. Examples are radar plumbing, wave-guide flanges, adapters, directional couples, connectors, dummy loads and antennae.

As a general rule the service requirements of electronic components do not require the high strengths available in brazed joints.[1] Normal design factors will satisfy most if not all brazed joints found in the electronics industry.

In addition to the metals and alloys commonly brazed, electronic components frequently contain metals or alloys having refractory oxide films, for instance aluminum bronze, beryllium copper and molybdenum alloys. In such cases special techniques are employed: cleaning procedures, special fluxes, heating methods and use of special alloys. Aluminum bronze requires the use of a special flux. Beryllium copper can be brazed in the solution-treated condition and then aged without serious loss of properties.[2] The brazing of molybdenum and high-molybdenum alloys is greatly facilitated by the use of silver alloys containing $^1/_2$ to 1% of phosphorus.

SPECIAL REQUIREMENTS OF THE ELECTRONIC INDUSTRY

With an industry which is growing rapidly even at present, it is difficult to list all of the special demands placed on brazing filler metals. Part of the difficulty stems from the reluctance of the electronics industry to discuss the details of the design and manufacture of the various components being brazed. However, the desire for small size and lower weight and the need for longer life under severe conditions of elevated temperatures and greater vacuum have placed restrictions on existing filler metals and have created demands for new ones.

One of the most important uses for brazing filler metals in the electronics industry is the joining of parts of vacuum tubes. The joints made must be leak tight

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Presented at the National Fall Meeting, AWS, held in Cleveland, Ohio, Oct. 19–23, 1953.

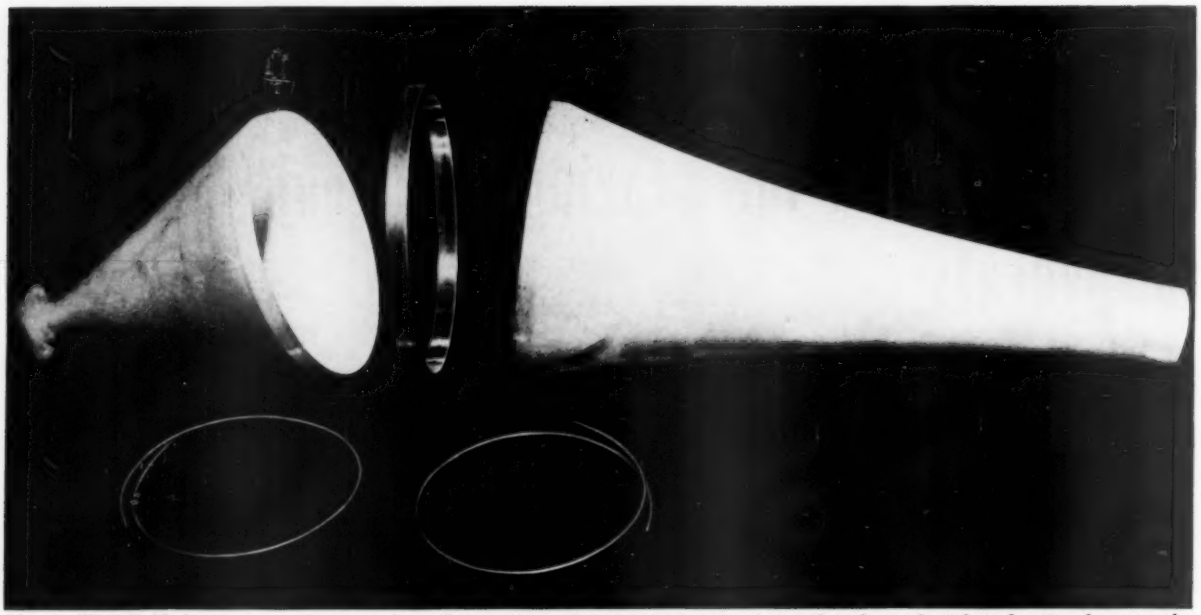

Fig. 1 This F-M dummy antenna consists of two silver-plated copper spinnings silver brazed with induction heat to the brass supporting ring using two rings of brazing alloy

and the filler metal in the joints must be free from elements which have high vapor pressures and which would volatilize under heat and vacuum, thus destroying the vacuum and contaminating the tube.

The narrow clearances in brazed joints and the small amounts of brazing filler metal used keep the size and weight at a minimum. The fluidity of the brazing filler metals—that is, their ability to wet metal surfaces and to flow into closely fitted components—enables them to be carried readily through a joint by capillary force. When proper brazing techniques are employed the required leak-tight joints are obtained.

Presence of impurities in the filler metals is suspected to be the cause of brazing difficulties. Certain impurities have been designated as detrimental by vacuum tube producers. Carbon, in particular, is undesirable because if present, it may leave a smut which can be seen on the joint surface. The principal source of carbon has been traced quite definitely to lubricant on the filler-metal wire. How much carbon, if any, is actually dissolved in and is an integral part of the alloy itself is not known, but it is low in any event.

The adoption of special handling in the mill will keep surface carbon at a minimum, but will not prevent contamination when making rings or other preforms. For best results "chemical cleanliness" is required; it is best obtained by cathodic electro-cleaning in a hot alkaline cleaner just before brazing.

The principal offenders as far as volatility is concerned are zinc and cadmium which elements are components of several but not all silver- and gold-alloy filler metals.

Table 1 lists boiling point and approximate vapor pressures at three separate temperatures for several elements found in filler metals with some additional elements given for comparison purposes.

Table 1—Approximate Vapor Pressures of Metals of Interest*

	Vapor pressures, mm mercury			
Metal	*400° C*	*800° C*	*1200° C*	*Boiling temperature, ° C*
Cadmium	2	>760	>760	765
Zinc	0.2	200	>760	906
Magnesium	<0.1	30	>760	1110
Lead	Low	>0.1	20	1740
Bismuth	Low	0.1	50	1420
Aluminum	Low	Low	0.4	2060
Silver	Low	Low	0.15	2210
Tin	Low	Low	Low	2270
Copper	Low	Low	Low	2600
Gold	Low	Low	Low	2970

* These figures were approximated from several handbooks.

The vapor pressures of zinc and cadmium immediately disqualify filler metals containing them for any applications where, after evacuation, the filler metal is to be heated, even moderately, either during fabrication or service. Although tin is known to have a low melting point its boiling point is high and its vapor pressure is low at intermediate temperatures. Tin-bearing brazing filler metals are highly useful for vacuum tube work. In particular, the alloy 60 Ag, 30 Cu, 10 Sn is the lowest melting of all the standard nonvolatile filler metals. There is a good record of commercial success with it, particularly in sequential brazing.

Whereas the standard limit of allowable impurities in silver-alloy filler metals is 0.15%[3], the limit for zinc plus cadmium in filler metals used in vacuum tubes is usually placed at 0.005%.

In addition to the higher purity filler metal, some users require the filler metal to be melted and cast in a vacuum and without a deoxidizer. This requirement is usually limited to those cases when the cost of a tube

Table 2—Silver and Gold Alloys for Vacuum Applications

Composition	Solidus °F	Solidus °C	Liquidus °F	Liquidus °C	Remarks
72 Ag, 28 Cu	1435	780	1435	780	AWS-A5.8–52T, BAg-8 (eutectic composition)
60 Ag, 30 Cu, 10 Sn	1095	590	1325	718	10% tin, silver-copper alloy
71.5 Ag, 28 Cu, 0.5 Ni	1435	780			Eutectic composition with Ni
90 Ag, 10 Cu	1435	780	1635	890	Coin silver
50 Ag, 50 Cu	1435	780	1650	899	500 fine
75 Au, 5 Ag, 20 Cu	1640	893	1650	899	18K red gold alloy
80 Au, 20 Cu	1620	882	1630	888	19.2K red, AWS-A5.8–52T, BCuAu-2
37.5 Au, 62.5 Cu	1710	932	1765	963	9K red, AWS-A5.8–52T, BCuAu-1
82.5 Au, 17.5 Ni	1740	949	1740	949	19.8K white
41.7 Au, 2.8 Ag, 55.5 Cu	1710	932	1765	963	10K red

is so high that extreme measures are considered justifiable to avoid any possibility of out-gassing or leakage which might be attributed to the filler metal itself.

Another phase of vacuum tube manufacture is the brazing of glass-to-metal and ceramic-to-metal seals. One of the most widely used sealing metals is the cobalt-nickel-iron alloy onto which glass is melted and to which another metal is frequently joined by brazing. This alloy and others of this same group are particularly susceptible to cracking during brazing at low temperature. This is not due, as commonly thought, to simple penetration of the grain boundaries by molten alloy. Rather it is a "stress corrosion" phenomenon wherein the molten filler metal is the corroding medium. The base alloy, if stressed while hot and wet by a brazing filler metal, fractures intergranularly and the filler metal flows into the cracks. In the absence of stress there is no intergranular penetration by silver alloy. When high-temperature brazing filler metals are used, stresses are relieved before the filler metal melts and the problem is obviated. When low-temperature filler metals are used, precautions must be observed to assure that the sealing metal is stress free or that stresses are relieved before the filler metal flows.

The silver- and gold-brazing filler metals most commonly used for critical vacuum applications are shown in Table 2.

Where vacuum applications do not exist, the most commonly used brazing filler metals are those shown in Table 3. This is an informative grouping only since the entire range of filler metals may be used where no composition restrictions exist.[3]

From the above tables it can be noted that there is a range of melting temperatures available in all groups of brazing-alloy filler metals. By selection of the proper filler metals, aided, in most cases, with good design features, it is possible to fabricate an assembly with several brazed joints. In this regard it should be noted that the gold-alloy filler metals are frequently used for the initial joints to be followed by the lower-temperature silver alloys. This process is known by the term "step" or "sequential" brazing.

A new method for direct brazing of ceramics to metal, the titanium hydride process, was first announced in 1947 by General Electric.[4] In this process, titanium hydride powder is applied (generally as a paste with a lacquer vehicle) to the ceramic surface to be bonded. A brazing filler metal such as copper, silver or silver-copper alloy is then melted onto the part either in pure dry hydrogen or in vacuum. During the heating the hydride decomposes and the titanium then dissolves in the molten brazing alloy; the titanium alloy thus formed wets and bonds to the ceramic.

Later, work at MIT[5] showed that vacuum-melted alloys of silver, silver-copper or other brazing filler metals with titanium or zirconium metals (rather than hydrides) could be used for direct brazing of ceramics. A very wide variety of ceramics could be bonded by these means, the principal difficulty being spalling of the ceramic due to differences in thermal contraction between the ceramic and the brazing-filler metal or ceramic and metal to which it is joined.

Our own observations have been that vacuum brazing is generally more satisfactory than hydrogen-furnace brazing; that high Al_2O_3 ceramics are relatively free of spalling despite expansion mismatches; and that with proper design and good vacuum, very strong, vacuum-tight joints between ceramic and ceramic or ceramic and metal can be made.

With the possible single exception of the brazing method for joining ceramic to metal, the basic fundamentals of metal joining are applicable to all silver- and gold-alloy filler metal joints in the electronic industry. Joint design, precleaning and assembling are some of these fundamentals but these are beyond the scope of this paper. The fundamentals of fluxing and heating are within this scope and will be treated herewith.

Table 3—Silver-Brazing Alloys—for General Purposes—Nonvacuum

Composition	Solidus °F	Solidus °C	Liquidus °F	Liquidus °C	Remarks
50 Ag, 15 Cu, 16 Zn, 18 Cd	1160	627	1175	635	Fed. Spec. QQ-S-561, Gr. 4
45 Ag, 15 Cu, 16 Zn, 24 Cd	1125	607	1145	618	AWS A5.8–52T, BAg-1
56 Ag, 22 Cu, 17 Zn, 5 Sn	1152	622	1205	651	AWS A5.8–52T, BAg-7

Fig. 2 The induction heating operation used in silver brazing the F-M dummy antenna

The elimination or prevention of oxide formation during the brazing process can be accomplished by the proper use of a suitable flux or reducing atmosphere. A wide variety of fluxes are available for brazing the silver- and gold-alloy filler metals. These fluxes will contain fluorides plus other ingredients to provide the required properties.

For fluxless brazing, the specific atmosphere will be dependent on the heating equipment used and the nature of the parts to be brazed.[6] At this point, however, it should be mentioned that many brazed joints made under controlled atmosphere conditions have been found unsatisfactory. One of the principal difficulties has been the fact that many atmospheres are not effective in the brazing range of some alloys. Another problem is the protection of the brazing-filler metal and the joint area until the assembly is heated to the temperature at which the atmosphere is effective. A third condition arises when entrapped air is admitted as the part to be brazed is charged into the heating zone.

The first of these problems is solved by the selection of the proper filler metal or atmosphere to suit the conditions of the part. In the latter two cases, a small amount of flux on the filler metal and the joint area is usually sufficient to satisfy the requirements until the atmosphere becomes completely effective.

Over the years, the greatest percentage of brazing with silver- and gold-alloy filler metals in jewelry, silversmithing and industry has been performed with the hand torch. Generally speaking, the above statement holds true for the present as it did for the past. In the electronics industry specifically, however, the various components have physical limitations which predetermine the type of heating which may be used.

Where possible and economically practical, a large volume of electronic production is brazed with a hand torch using a suitable fuel gas with air or oxygen. The factors which determine the selection of the hand torch as a heating medium are the same as those in all industries. Radar plumbing, antenna mast and components and various small subassemblies lend themselves readily to this heating method. The final assembly of many separately brazed subassemblies where heat control by the operator is desirable is another condition for which torch brazing is suitable.

For furnace brazing, both the batch type and the conveyor type are widely used. Although the furnace is most commonly associated with a controlled atmosphere, there are many applications where flux is the only means of eliminating oxidation. Since furnace brazing operations require over-all heating of any assembly, accurate temperature controls are essential to prevent overheating of critical parts. This is especially true in the case of step or sequential brazing. Here it is necessary to keep all subsequent brazing temperatures below the melting point of the alloy previously used.

Resistance heating and high-frequency induction heating methods are quite similar when these methods

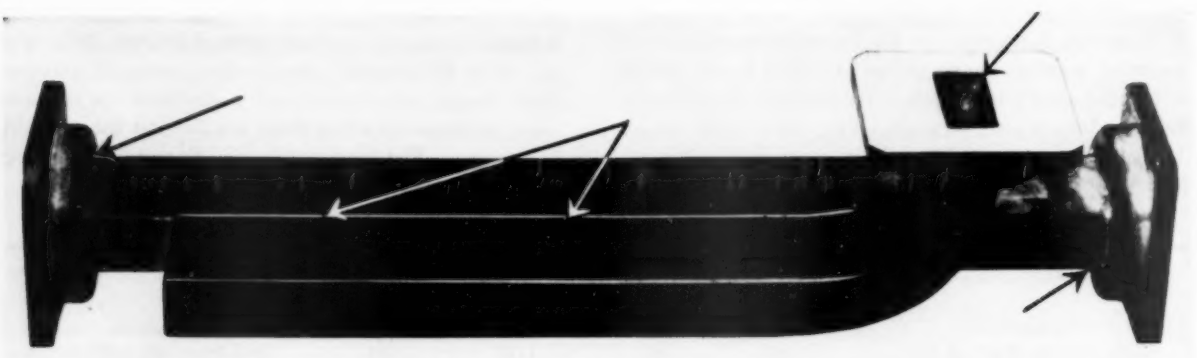

Fig. 3 A typical directional coupler of copper rectangular wave-guide tubing and flanges is hand-torch silver-alloy brazed and held to very close tolerances

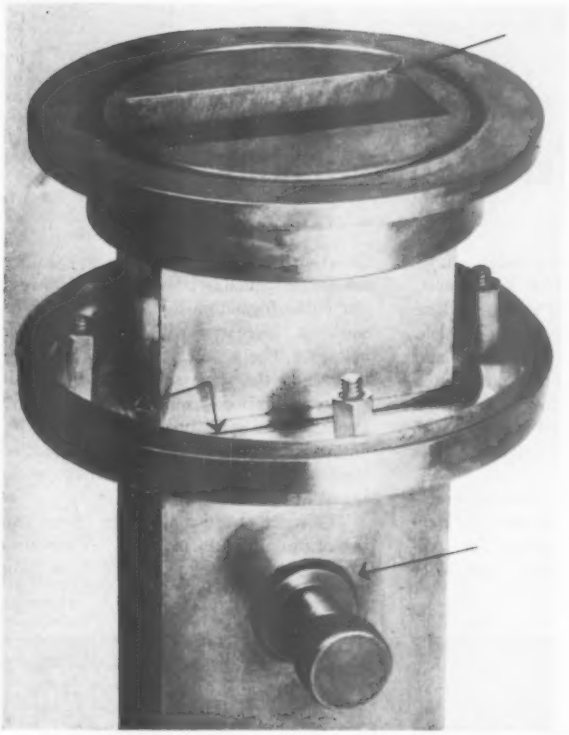

Fig. 4 This illustrates the type of smooth silver-brazed joints obtained on wave-guide assemblies

are used for brazing in an atmosphere or in a vacuum. A suitable bell jar covering the work and the heating element, is used to exclude the normal atmosphere. The controlled or protective atmosphere can then be introduced or the necessary amount of vacuum created. An important extra advantage of this method is full visibility of the brazing operation.

Where neither vacuum nor protective atmosphere is required, the induction and resistance equipment are used with flux. This technique is the standard procedure used with these heating media for silver-alloy brazing.

Another method of heating which has found acceptance in electronic component production is the molten salt bath. This method is limited to those assemblies on which the brazing alloy can be preplaced away from direct contact with the heat. Certain types of radar plumbing, mounting bases and similar parts lend themselves to this form of heating. While internal ring grooves may be used with other forms of heating, they are a "must" in salt bath heating.

SUMMARY

As has been pointed out, the rapidly growing electronics industry involves many unique problems in metal joining. It has been indicated that the characteristics of the silver- and gold-brazing filler metals have helped in solving some of these problems. The tables listing the presently used filler metals should be of definite help in selecting the proper composition for various types of assemblies. The range of melt and flow points available help solve the frequent problem of sequential brazing at varying furnace temperatures.

Special emphasis has been given to the more difficult problem of the brazing of vacuum tube components with "vacuum grade" silver and gold alloys.

The type of heating equipment used varies with the nature of joints. It has been indicated that many of the standard heating methods are used plus such specialties as fluxless induction or resistance brazing enclosed in bell jars with either a vacuum or very carefully controlled reducing atmospheres.

Silver- and gold-alloy filler metals have the desirable characteristics necessary for enabling the electronics components manufacturers to assemble their parts to the very close tolerances they require with the neat appearing and easily silver-plated joints specified on many of the wave-guide assemblies.

Research is continuing on the development of even better alloys and better brazing methods in order to keep up with this fast growing industry. Another year or two will reveal a great amount of additional information on the uses of silver and gold alloys in joining electronics assemblies.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of the Handy & Harman Technical Laboratory at Bridgeport, Conn., in the preparation of this paper. In addition, the Engineering Department of Sperry Gyroscope, Long Island, N. Y., and Amperex Electronics, Brooklyn, N. Y., were of valuable aid in outlining the scope of this treatise.

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Inspection Techniques for Quality Welding

Discussion by Herbert R. Isenburger

It is always pleasing to hear from users that radiographic inspection "has proved a most effective means of checking welds." Since radiography is the writer's specialty, we will confine our remarks to that field.

The authors state that "little was done in this field (gamma-ray inspection), on either side of the Atlantic, until 1928." The original work with radium was carried out in 1925 by Pilon and Laborde in France. They used this material on board ship to radiograph heavy steel castings, among other materials (Electricité et Mécanique, July/August 1927, pp. 25–38).

Long before the Government installed a 200-kv X-ray unit at Watertown Arsenal, Dr. Ancel St. John had done the pioneering work on weld inspection. He was the first one ever to be employed fully on radiographic work when the Union Carbide & Carbon Research Laboratory engaged him in 1918, and where he remained in that capacity until he opened his own laboratory in 1925. A typical exograph and the technique of that early period (1920) are reproduced on page 132 in Industrial Radiology (John Wiley & Sons, New York, N. Y., 1943). St. John's pioneering work led to a patent (No. 1,622,149) assigned to the Carbide company.

The names of two other pioneers in the radiographic welding field deserve to be mentioned: H. Pilon and John T. Norton. Dr. Pilon presented his findings in an important lecture on "Metal Radiography and Its Application to Autogenous Welding" in Paris, on July 1, 1921 (published by the Library of Acetylene and Autogenous Welding, 104 Boulevarde Clicky, Paris, Feb. 11, 1922). Some of Professor Norton's work was published in the *Iron Age* (1926, Vol. 118, pp. 409–412) and the *Technical Engineering News* (December 1926, p. 263). The writer himself takes credit for providing much of the preliminary work which led to the Boiler Code specification in 1930.

At least 90% of all radiographic problems in the welding industry today can be solved by a modern 260-kv X-ray unit, since only about 10% of all welding is done in plate stock greater than 3 in. thick. This eliminates the use of million-volt and betatron installations which would be too costly for the average welding shop. Such equipment is mostly used on ordnance material and requires a building of its own.

Although an even more powerful radiation can be obtained by the 80-Mev synchrotron, very little is gained for radiography in the higher voltage range, since the absorption of radiation in metal does not change much between 10 and 50 Mev. For equal focus-film distance the field of coverage decreases with rising electron voltage. The sensitivity and latitude are essentially the same through steel for all energy radiations from 10 to 50 Mev. Penetrameter sensitivities of 2% at 1 in. and progressively down to 0.5% on 9 in. of steel can be expected with a betatron operating at about 15 Mev.

The authors quite correctly ignore the use of radium and Cobalt 60. These materials are ill-suited for weld inspection

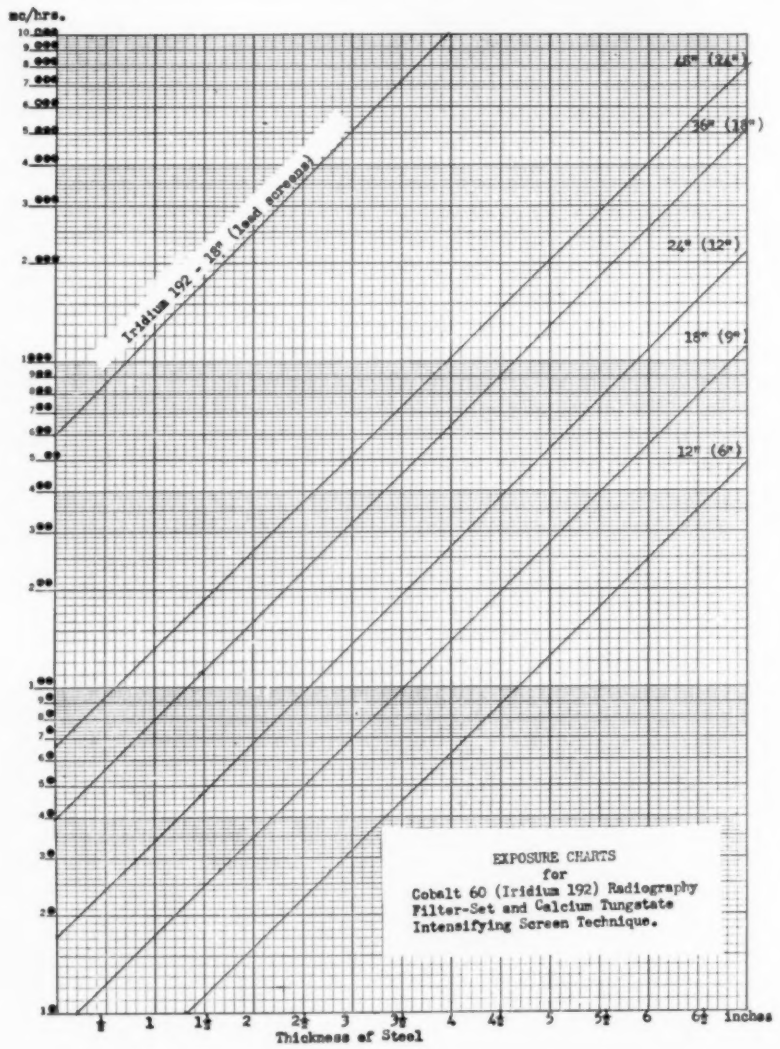

Figure 1

Herbert R. Isenburger is with the St. John X-Ray Laboratory, Califon, N. J.

Paper by Lew Gilbert and William B. Bunn was published in the July 1953 issue of THE WELDING JOURNAL, pp. 614–619.

Table 1—Gamma-Rays* *Sources* or Gamma-Ray *Emitters*

Element	*Atomic number*	*Mass number*	*Half-life*	*Gamma-ray energies, Mev*	*Output/mc mrhm/mc*	*Useful thickness, range, steel in in.*
High energy						
Natural:						
Radium	88	226	1620 yr	0.24–2.42 (0.7 mean)	0.84	$^1/_2$–6†
Radioisotopes:						
Sodium	11	24	15 hr	1.38 and 2.758	...	1–10
Scandium	21	46	85 dyas	0.89 and 1.12	1.1	$^3/_4$–6
Cobalt	27	60	5.3 yr	1.17 and 1.33	1.3	$^3/_4$–6†
Antimony	51	124	60 days	0.6 (95%), 0.714 (24%), 1.7 (70%), 2.06 (6%)	1.2	$^1/_2$–6
Tantalum	73	182	111 days	0.152 (2%), 0.222 (4%), 1.189 (37%), 1.225 (57%)	0.61	$^3/_4$–6†
Europium	63	152, 154	13 yr	0.12 to 1.2	0.55	$^1/_2$–6
Cesium	55	134	2.3 yr	0.568 (25%), 0.602 (100%), 0.794 (100%)	1.15	$^1/_2$–3
Medium						
Radioisotopes:						
Antimony	51	125	2.7 yr	0.035 to 0.637	0.72	$^1/_4$–2
Cesium	55	137	37 yr	0.662 Beta: 1.2 (5%) and 0.51 (95%)	0.37	$^1/_{16}$–2
Iridium	77	192	74 days	0.137 to 0.651 (0.35 mean)	0.27	$^1/_{16}$–2
Selenium	34	75	127 days	0.067 to 0.405	0.30	$^1/_4$–1$^1/_2$
Low						
Radioisotopes:						
Cerium	58	144	290 days	0.13 (strong)	...	Aluminum
Thulium	69	170	127 days	0.085 (10%); Beta 0.97	0.0045	Aluminum

* Recommended lead thickness for shipping containers:
Co^{60}: 3 in. Pb up to 250 mc; 4 in. Pb 300–500 mc; 5$^1/_2$ in. Pb 500 mc to 1 c.
Ir^{192}: $^1/_2$ in. Pb up to 500 mc; 1 in. Pb 500 mc to 2 c.

† Greater thicknesses may be penetrated successfully by using larger amounts of Ra, Co^{60} or Ta^{182}, but these require remotely controlled handling devices for safe operation.

unless used in conjunction with a filter-set and calcium tungstate screens. Figure 1 gives the exposure charts for focus-film distances of from 12 to 48 in. when using Cobalt 60, for this new technique. In Iridium 192, however, we have a radioisotope which will give adequate results for weld inspection. With its lower-energy range gamma rays (0.35 Mev mean), Ir^{192} is suitable on steel plate ranging in thickness from $^1/_{16}$ to 2 in., and is specially useful for short-distance work inside pipes, etc. While its half-life is short (74 days), it can be reactivated. It is sound practice to use three sources in rotation; while one is in use, two others are in transit and being processed. A suitable source of Ir^{192} has an activity of 2 curies with a pellet size of 1 × 1 mm. It must be produced in a position of high intensity flux to provide satisfactory radiation. Figure 1 also gives exposure charts for Iridium 192 for focus-film distances of from 6 to 24 in. with the new filter-set and salt screens technique. The time saving of this new method is evident from a comparison of the two exposure curves at 18-in. distance shown in Fig. 1. Whereas the old method, employing lead screens, requires 1200 mc/hr to radiograph a 1-in. weld, the new method only requires 70 mc/hr.

A promising new isotope is Cesium 137, a uranium fission product. The sources are approximately 2 mm in diameter and contain about 200 mc of Cs^{137}. The 37-year half-life is a great advantage and its gamma radiation is monochromatic (0.662 Mev). There are a number of other gamma-ray emitters which may be suitable for weld inspection. They are shown in Table 1. And since the use of isotopes is steadily increasing, a comparison between advantages and disadvantages for X-ray equipment and radioisotopes is given in Table 2. (Both tables are taken from an article on Industrial Radiography which the writer prepared for the *Encyclopedia of Chemical Technology* to be published in Vol. 11, and are preprinted here through the courtesy of Interscience Publishers, Inc., New York, N. Y.)

Table 2—Comparison Between X-Rays and Gamma Rays

X-ray units	*Gamma-ray sources*
	Advantages
Shorter exposure time	Can be shaped to any desired form before being activated
	Small and light—can readily be transported and used when and where needed
	Can expose a number of objects simultaneously (Carrousel exposures)
	Do not require attention during exposure
	Easy to manipulate
	No scattering effect to be considered
	Disadvantages
Great expense	Cannot be turned off
Great bulk	Long exposures
Repair and upkeep cost	
Require power supply	
Skilled operators	

Authors' Reply

The authors are complimented that Mr. Isenburger, an outstanding authority in the field of radiographic inspection, has read and submitted comments on our rather elementary paper.

We bow to Mr. Isenburger's knowledge of the pioneer work in this field performed by Dr. Pilon and Dr. Laborde in France, and of Dr. Ancel St. John, Professor Norton and Mr. Isenburger in this country. Any mention of the pioneering work in radiographic inspection of welds is certainly incomplete without reference to these men who contributed so greatly to its advancement.

As users of radiographic inspection we are indebted to Mr. Isenburger for his tables and explanation of the use of some of the newer radioisotope sources. In concise form they give a most complete picture of the present status of radiographic energy sources available to industry.

Inspection Techniques for Quality Welding

Discussion by R. J. Kriz

Having had intimate contact with practically every type of inspection except the baby of them all as referred to by the writers as "Ultrasonic Inspection," I feel the paper is well presented.

There are one or two comments I would like to make. In the authors' reference under "Codes and Specifications" the statement has been made that there should be little difference in cost between sound good quality welds and poor inferior welds since the same motions are necessary to obtain both. I am rather inclined to disagree with this statement as I feel that it takes considerably more time to fit up properly and prepare welded joints and considerable time is cut from a job by slipshod methods of fit-up and the elimination of certain necessary jigs.

Also, I have in the past been quite concerned about the method of welding pipe in a fixed horizontal position whereby the welding is done downhand. This method will produce welds from three to five times faster; however, there is a question in my mind as to whether the resultant weld is as good as the weld when welded from the bottom up.

Under the heading of "Visual Inspection" a question arises in my mind regarding the statement made that there is usually little question about the "type of defect, or dimensions of either welds or assembly during visual inspection." It is my conception that one of the inspector's toughest jobs is to decide at the time the defect is observed as to whether it is serious enough to accept as is or whether it should be removed.

I can recall that in the early 1930's, when X-ray was coming into its own, that we, as a laboratory, had many a rough time in the interpretation of films with outside inspection agencies as to the extent of the defects and whether they were permissible or whether they had to be removed and rewelded.

I also got quite a charge out of the photograph showing inspection on the inside of welded seams of steel pipe as it brought back memories of many, many miles of pipe which I had inspected at various plants such as American Rolling Mill Co. and Bethlehem Steel Co. This not only involved inspection but a training program for welders who handled the repair work on such weldments, and once again considerable discussion would ensue as to what was an acceptable undercut or defect in the weld, necessitating its removal.

R. J. Kriz is Secretary-Treasurer, Cleveland Section, AWS.

Paper by Lew Gilbert and Wm. B. Bunn was published in the July 1953 issue of THE WELDING JOURNAL, pp. 614–619.

Discussion by Robert Chuse

When I was first asked to write a discussion on a paper by Bill Bunn and Lew Gilbert, I said to myself, what could these welding experts possibly have left out in writing a paper on "Inspection Technique for Quality Welding?" Upon reading the article in the July issue of THE WELDING JOURNAL, I discovered that it is a good paper but that a few things could have been added. For instance: The first section should have been called "Inspection of Welding Procedures," as I consider a proved procedure the basic part of sound welding.

Basically, what is a "Welding Procedure?" It is proof by a manufacturer that he can successfully weld a particular type of material. The Inspector should satisfy himself that the manufacturer's procedure is acceptable for welding the job to be constructed. But the Inspector's job is not finished there. He must see that the welding operators have passed the operators test proving he can use the manufacturer's procedure in welding this material. And finally, the Inspector should see that the procedure is followed in the shop. This is particularly important in an *Incentive Wage System* shop where a time limit is set for certain type welds and a bonus is given if a weld can be completed faster than the set standard time.

In the section on "Codes and Specifications" a few words of praise certainly should be said about the ASME Welding Codes. They have done so much to set a good standard in the welding industry that many a purchaser of pressure vessels who does not have an inspection department of his own is thankful that he can order an ASME Code vessel and have it inspected to Code standards.

The section on "Testing and Inspection Methods," is well written, especially the part on visual inspection, and needs no further comment.

In the part on "Radiographic Inspection," it is nice to know the history of radiography, but the important thing is to be able to interpret the X-ray or gamma-ray films. Not enough inspectors can properly interpret these films and it might be stated that some of the X-ray technicians could use a little more knowledge in film interpretation. I have in many instances requested that X-rays of a welded seam be retaken. The retaken films proved that either the technique in taking the film or the interpretation of the original films were wrong. Basically, the important parts from the Inspection point are these:

Has the X-ray of the weld been properly taken?
Has complete penetration of the weld been gotten?
Are the defects that can be seen acceptable or must they be chipped out and repaired?

Robert Chuse, 229 Hillside Ave., Leonia, N. J.

The parts of the paper on "Magnetic Powder Inspection," "Fluorescent or Dye-Colored Oil Penetrant Testing" and "Ultrasonic Inspection" leave little to be added.

In addition to the above in which I tried to follow the outline of the Authors' paper, something should be said about design. The Designing Engineer can help in producing good welding. The designer should take into consideration the accessibility and position that the joint is to be welded in. For example: On the point of accessibility alone, if it is difficult to weld a joint because a welder cannot reach it and see it and relax at the same time, it is impossible to expect and get good workmanship as a result. It is therefore important to start the inspection by checking the drawings. It is here that difficult-to-weld joints can be seen and possible corrected before fabrication is begun.

In conclusion, I would like to emphasize the following statement in the Author's words: "Actually there should be little difference in cost between sound, good quality welds and poor inferior welds since the same motions are necessary to obtain both."

How few shops realize this; the worst offenders often being the most cost conscious. It, therefore, actually saves money to so organize their own inspection departments to get good quality welding, because welding, more than any other process, requires the utmost in control.

Authors' Reply

The discussion of our paper by both Robert Chuse of the Hartford Steam Boiler Insurance Co. and Robert Kriz of the James H. Herron Co. have been carefully read and are hereby gratefully acknowledged. To merit the attention of two such well-known people in the inspection field and to read the very nice comments of both of them is certainly gratifying to both Mr. Gilbert and Mr. Bunn.

It is interesting to note that both Mr. Chuse and Mr. Kriz mention specifically the section on "Codes and Specifications." The authors agree to both criticisms concerning the coverage of that particular section. There is no doubt that the importance of ASME should have been emphasized and the fact that it was not is merely because both authors feel the same and the importance of the ASME welding codes are beyond question.

It is interesting also to note that both discussers mention the section in which the authors point out that, "There should be little difference in cost between sound, good quality welds and poor inferior welds since the same motions are necessary to obtain both." Since Mr. Kriz was the only one who took exception to that statement, perhaps this reply could best be directed to him. What the authors mean here is that it really makes no difference from a cost standpoint because a sloppy, slipshod job of fit up and the elimination of necessary jigs, and carelessness in the fabrication of the weldment will result in rejections, repairs, cutouts and other such expensive items. What the authors mean to imply here is that careful attention to all of the details as mentioned by Mr. Kriz result in a good quality job. And though these careful details may be somewhat more costly in their original form, they eliminate the excessive cost of rejections and repairs and are, therefore, just as inexpensive as spending less time and attention to the problem originally. So basically, both the authors and Mr. Kriz are in agreement on this point. Mr. Kriz mentions also the practice of welding pipe in a fixed horizontal position and specifically points out that he frowns on such a practice. It is logical that someone as close to inspection as Mr. Kriz obviously would frown on such a practice. But it must be remembered that much of the welding done on pipe is not necessarily of such quality that radiographic or other types of critical inspection are necessary. Much pipe welding can be done, and is done very efficiently, by that method. And much of that type of pipe welding requires no particular inspection other than good careful visual inspection on the part of a well-qualified operator and/or inspector.

So basically, both Mr. Kriz and the authors are right in their respective opinions of this method of pipe welding.

It is interesting to note that both discussers have different opinions about the section under "Visual Inspection." Mr. Chuse who certainly has had considerable experience in visual inspection feels that the subject matter has been covered adequately. By the same token, Mr. Kriz who also has had many years of different types of inspection feels it was not covered adequately. His point is well taken, and it is certainly advisable that the inspector know what he is looking for when he does an inspection job of any kind. Assuming that he does however, the authors feel the subject matter has been covered adequately. If the inspector does not know his business, and the possibilities are that there are many such inspectors in the field, then the problem becomes a much more serious one. And frankly, the scope of this paper does not allow a thorough discussion concerning the proper training of such inspectors. The problem of "how good is good enough" has always been with us, and will probably ever be with us, at least until such time as inspection agencies and/or fabricators decide upon a carefully planned, easily distinguishable standard for such inspection. And the time for such a standard apparently has not yet arrived.

The authors are gratified that so many qualified inspection people have taken the time to comment on their paper. It is an excellent commentary on the reading habits of people in this industry that a paper such as this should have received such wide and interested readership. As the industry grows, one of the primary reasons for this growth will be the continuing interest of such people in papers of this kind.

Arc Characteristics for Consumable-Electrode Gas-Shielded Welding

An experimental investigation of the inert-gas-shielded metal arc in order to establish the volt-ampere curves for different metals

by R. W. Tuthill

IN THE development of Fillerarc equipment* for the consumable-electrode gas-shielded welding process, an intensive study was made of the arc itself. This process is radically different from other methods of welding. New concepts of current density and adjustment, electrode feeding methods, control of arc length, travel speed and operator skill requirements become apparent and should be expected.

One phenomenon of the new method of welding is the manner in which metal drop particles transfer across the arc. As the current density is increased on the electrode, the droplets forming at the end of the wire electrode decrease in size and increase in rate to the point where they cease to short circuit the electrode and work at any instant. At normal arc lengths the current density at which this transition from large to small droplets occurs is high, about 30,000 amp per sq in., on large electrodes ($^3/_{32}$ in. diam); and becomes increasingly higher, 200,000 amp per sq in., when using smaller electrodes (0.030 in. diam). With these high current densities and feeding rates, travel speeds are also proportionally higher compared to metal arc welding. The rapidity with which the operator can move the gun uniformly along the joint sometimes is the only criteria as to how fast a travel speed can be satisfactorily used. These current densities are much greater than those used in conventional flux-coated electrodes and result in the fundamental difference that produces the unique welding characteristics of this new rapidly expanding process.

These high current densities cause rapid burn-off rates of the electrode. The current is controlled by adjusting the feeding speed on the electrode rather than adjusting the welder.*

Another major reason for undertaking this basic investigation of the process was to determine what improvement could be made toward reducing the operator skill requirement, which is a large factor when using conventional welders in consumable-electrode gas-shielded welding. The test results obtained produced the data which resulted in a motor generator design which would provide the ultimate in the reduction of the skill necessary for welding.

Since the output curve of the welder determines the arc length, a study of the arc was in order to determine arc characteristics before designing a welder specifically for this process.

Elaborate tests were made to determine how the arc length varied with arc voltage under different conditions of welding. These tests were made in order to design a generator so that it would provide the correct arc length regardless of the wire feeding speed.

An experimental investigation was undertaken to study the arc in order to establish the characteristic volt-ampere curves for different metals. The schematic diagram of the test equipment is found in Fig. 1. This shows the relative position of the camera for arc length, the fixed gun, moving workpiece, wire drive unit and welder. The electrode wire was fed through a gun by pulling it with knurled feed rolls in the gun itself.

The main object in this investigation was to determine the relationship between the physical arc length and the arc voltage for different welding conditions. The practical way selected to measure arc length was to project the image of the arc upon a calibrated screen. A camera with a ground-glass viewing plate was focused on the arc in the plane of the work. The arc length was measured from the solid end of the wire (where droplets were forming) to the work. This procedure did not take into account the arc length that was below the surface of the plate in the arc crater. This effect was minimized as much as possible by using a heavy workpiece. At very high currents, however (about 350 amp), the center of the arc crater was never more than $^1/_{16}$ of an inch below the surface of the plate. True arc length may be somewhat higher under these conditions, but the purpose of these tests was to determine general arc characteristics.

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Presented at the AWS National Fall Meeting, Oct. 19–23, 1953, held in Cleveland, Ohio.

* See "Fillerarc Welding Process," article by the author in THE WELDING JOURNAL, **32** (8), 703–707 (1953).

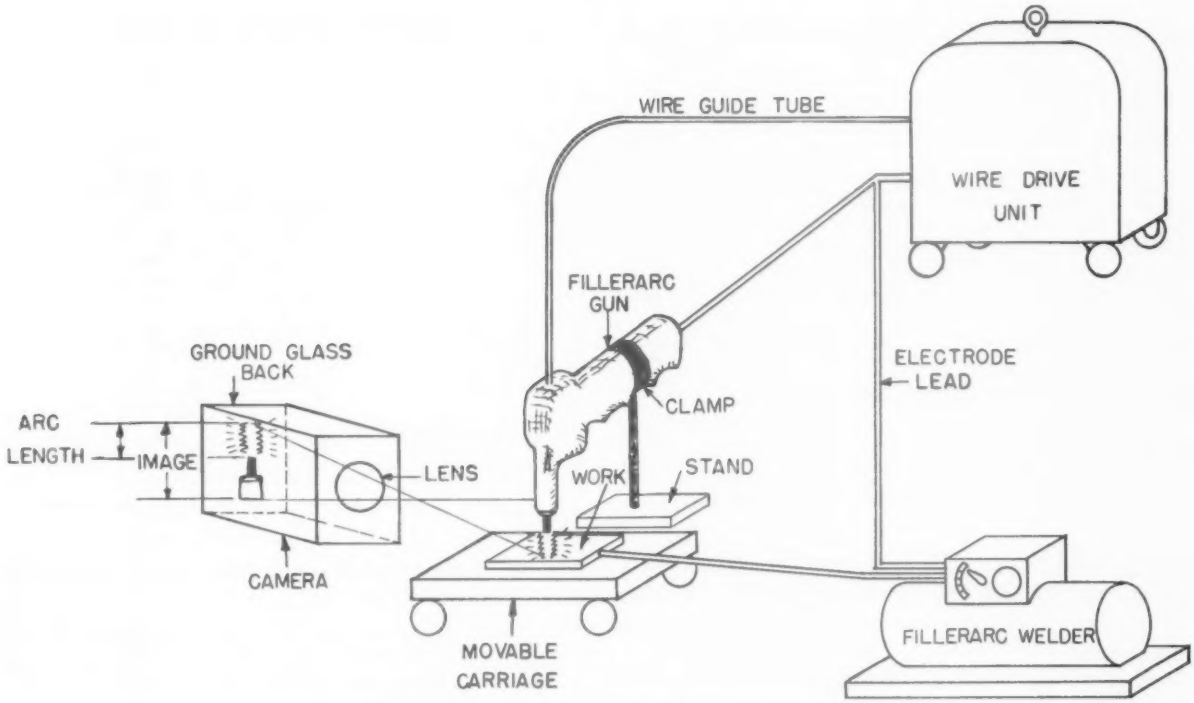

Fig. 1 Fillerarc welding test arrangement

The gun was positioned in front of the lens system of the camera and adjusted so that the inverted arc image was double size for accurate arc length measurement. The work was positioned under the gun so as to move at adjustable speeds while the gun remained fixed. Although conventional and special welders were used as sources of power, the selection of welding power source had no effect on the data obtained.

The test procedure was to start the arc by feeding the electrode, this started the arc automatically, producing a bead on the work which moved under the arc. At the same time, readings of all pertinent data were taken including arc current, arc voltage, arc length and wire feeding speed. Readings were taken at different arc lengths by adjusting the output curve of the power supply so as to produce the needed current to consume the wire at different arc voltages. The arc voltage was measured from the copper contact tip to the work. The contact tip is the last metallic part of the gun in contact with the electrode. There is an element of voltage drop in the wire itself, as much as 3 volts under some conditions of high currents, which contributed to the arc voltage. The reason for factoring the voltage drop into the characteristic of the arc was that this drop contributes to the requirements of the arc as far as the machine design was concerned. From these data, curves of arc length versus arc voltage were plotted as in Fig. 2. These curves show that as the physical length of the arc is increased, the arc voltage also increased. This was expected, since most prior art in other processes indicates that this is true. Wire feed in inches per minute is indicated for each curve. However, the current remained almost constant, regardless of arc length, provided welding is above the dripping transfer stage. This is a fact of great significance. As the arc length is increased with the same wire feeding speed, the current needed to maintain the same burn-off rate increases very little. In many other processes the effect of arc length (arc voltage) on burn-off rate is considerable. The difference in current to consume the wire at a constant rate in this process varied only about $\pm 5\%$ with long or short arcs. With small wire at very high current densities the required current for burn-off equilibrium remains practically constant even with extreme changes in arc length.

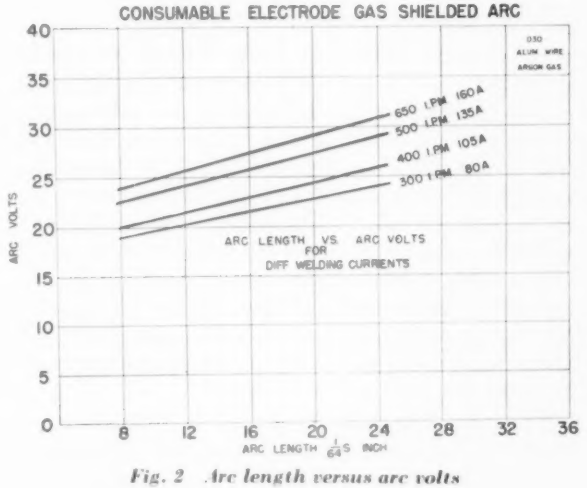

Fig. 2 Arc length versus arc volts

Using the data from a series of tests at different wire feeding speeds (current), the curves were replotted, arc

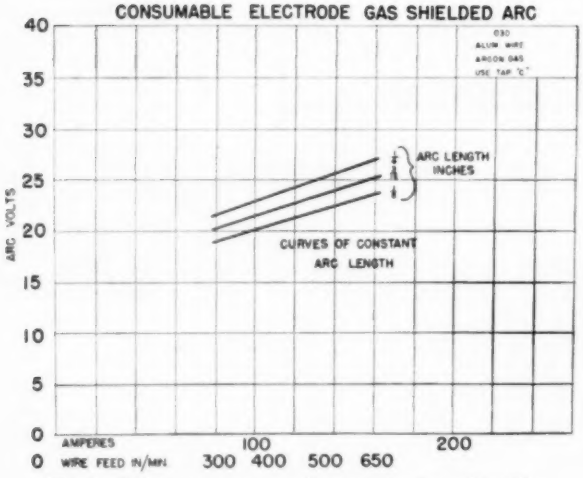

Fig. 3 Volt-ampere curve for constant arc length

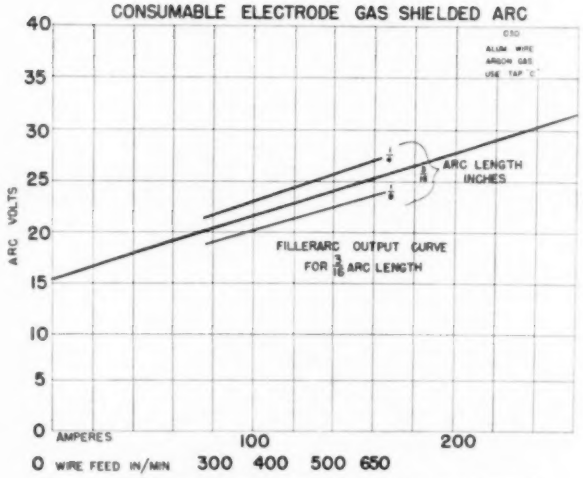

Fig. 4 Fillerarc output curve for 3/16-in. arc length

voltage versus wire feeding speed (arc current), for a constant arc length. This gave a family of curves such as shown in Fig. 3 for 0.030-in. diam aluminum wire in argon gas.

As may be seen from Fig. 3, the curves of constant arc length are rising. This means that in order to maintain a constant physical arc length the arc voltage must be regulated so as to be increased as the wire feeding speed is increased. In consumable-electrode gas-shielded welding, unlike metal-arc welding, it is not possible for the welding operator to make any permanent change in the arc length by manipulation of the welding gun. Instead, the arc length is adjusted by controlling position of the output volt-ampere curve of the welding generator. These curves helped to explain why it was so difficult to use a conventional motor-generator welder for a power supply for this process. The arc and conventional welder output curves are almost perpendicular to each other and are entirely mismatched. This results in a conventional welder being critical in adjustment, requiring long set-up time and considerable operator skill.

These were the basic data that were desired. It was apparent that the same arc voltage could be obtained in the arc with several different arc lengths. This showed that arc voltage and current were really dependent variables depending upon wire feeding speed, and arc length.

It was then reasoned that if a welding generator for this process had an output curve that was also rising and matched the curve of constant arc length, that no matter what the current needed to make the burn-off rate equal feeding speed, this current would be produced automatically and at a constant arc length. A generator was designed using this theory and was found to be entirely satisfactory. When the machine volt-ampere curve matches the arc volt-ampere curve, as in Fig. 4, for a $^3/_{16}$-in. arc length, the wire feeding speed could be changed from maximum down to minimum without changing arc length at all! The arc length is adjusted by positioning the output curve higher or lower by means of a field rheostat which changes the open-circuit voltage.

This type of machine also has a minimum of load drop-off compared to a conventional welder and is not affected by changes in primary line voltage.

One major cause of load drop-off in a conventional motor-generator welder is the heating of the control fields. This results in a drop in open-circuit voltage and current output setting. This cause of load drop-off was practically eliminated by using two control fields in opposition to each other; thus heating effects on open-circuit voltage and output were effectively canceled out.

Since it was necessary to make the new welder suitable for all metals with this process, a comprehensive arc voltage study was made for many different metals and different gas combinations to determine the range and slope of the common arc volt-ampere curves. After plotting the data as in Fig. 2 for each combination of wire and shielding gas, the data were replotted in the form similar to Fig. 3. A few of the curves for different metals are shown in Figs. 5, 6 and 7, with only those curves for $^1/_4$-in. arc lengths being shown for the sake of clarity. However, it is to be understood that each of these curves is one of a family of curves for different arc lengths similar to Fig. 3.

Using the data from these tests, the final design of the motor generator was then undertaken. In order to match the volt-ampere curves of the arc, it was found desirable to make the welding machine so cumulative-wound as to make it practically a series generator. Controls were supplied on the machine to select one of four different rising slopes and field control was provided to raise the whole output curve up and down to change from one arc length to another for different applications. Four different generator output curves were needed to substantially match all the slopes of volt-ampere curves for different wire and gas combinations.

The curves in Fig. 5 are plotted with the proper output curve of the welder matching the arc curve.

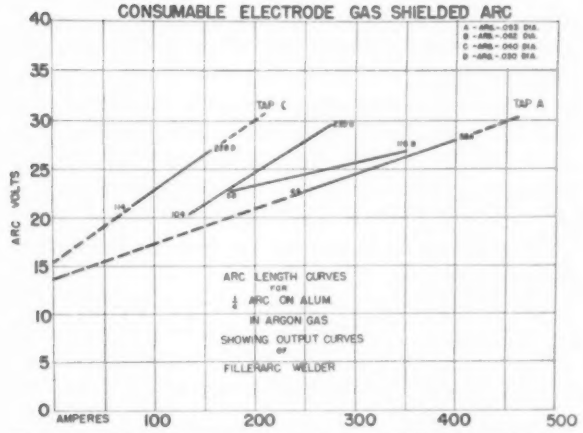

Fig. 5 Volt-ampere curves wire of different diameter showing fillerarc output curves

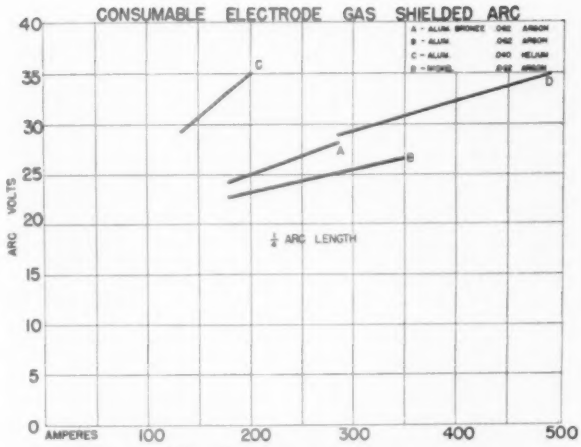

Fig. 7 Miscellaneous volt-ampere curves

Adjustment of the welder output slope is made by using a switch to select the proper cumulative series field tap so as to match the output of any arc curve.

Figure 5 shows how the output curve matches the curve for 0.030 aluminum $^1/_4$-in. arc on Tap C. It also illustrates the adjustment of the output curve for a $^1/_4$-in. arc for $^1/_{16}$-in. aluminum, using Tap A. By raising or lowering open-circuit voltage with the dial, the arc length can be lengthened or shortened to suit the welding conditions. Note how the steepness of the slope of the volt-ampere curve becomes less as the diameter increases. At the same time, it will be noted that as the wire diameter became smaller, the current density must be increased. The numbers at either end of the arc curve are the current density in thousands of amperes per square inch. The range of current shown is that which is practical for proper welding. In each case the low current end is just above the dripping transfer point.

Aluminum wire as small as 0.015 has successfully been used in welding tests in the laboratory. Very high wire feeding speeds, about 1000 ipm, are needed in order to permit sufficient current to flow, 50 amp, for proper arcing. At these currents $^1/_{32}$-in. aluminum is readily welded.

As in the tungsten arc process, the arc voltage when using helium is higher than with argon and somewhat steeper. Mixtures of these gases result in a volt-ampere curve between that of argon and helium alone.

The curve for stainless steel is shown in Fig. 6. The effect of mixing oxygen with the argon is to lower the volt-ampere curve and make it somewhat less steep. Oxygen-argon mixtures seem to produce more satisfactory welding results than pure argon when used on either straight or reverse polarity. If straight polarity is used with oxygen-argon mixtures, the arc voltage curve is still lower, as shown in Fig. 6.

In Fig. 7, curves are plotted for nickel, aluminum bronze and aluminum wire in argon gas. Comparing the same diameter wire, curves for aluminum and aluminum bronze have about the same slope but different values of voltage.

The operating technique in using this new motor-generator welder is to select the slope desired for the wire being used in accordance with a chart, shown in Table 1, supplied with the welder. A dial calibrated in arc length is then used to adjust this factor. Figure 8 illustrates how radically new this Fillerarc welder is. It has no current calibration markings on the control dial at all! Current cannot be adjusted in this process by an adjustment of the welder—only by adjusting the wire feeding speed.

In order to weld with the new Fillerarc rising characteristic welder, all that is necessary is to feed the wire—

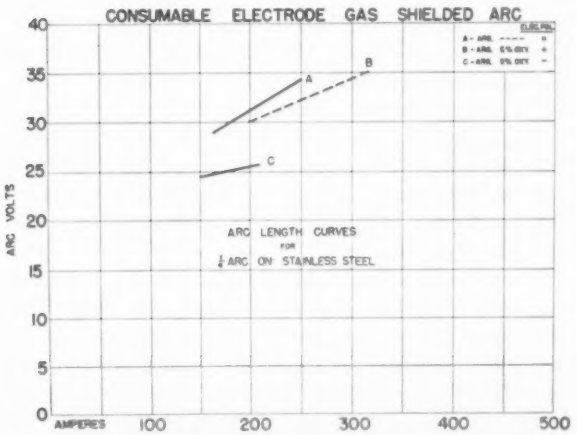

Fig. 6 Stainless steel volt-ampere curves

Table 1—Welding Range Chart

Wire diam, in.	*Gas polarity*	*Argon reversed*	*Oxygen Argon straight*	*Argon Oxygen reversed*
0.030–0.040	Aluminum	C	Not used	Not used
$^1/_{16}$	Aluminum	A	....	....
$^3/_{32}$	Aluminum	A	....	....
0.030–0.040	Steel alloys	C	D	D
$^1/_{16}$	Steel alloys	A	A	D
$^3/_{32}$	Steel alloys	A	A	D
0.062	Aluminum bronze	D	Not used	Not used

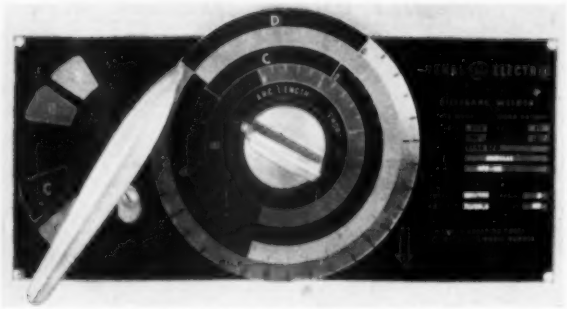

Fig. 8 Dial of new fillerarc welder

the correct current will be automatically supplied to burn off the wire at exactly the rate it is being supplied. Furthermore, this new welder does this at a constant arc length as the wire speed is adjusted (while welding, if desired) to give more or less heat to the arc. Compared to a conventional welder, this new type self-regulating welder requires less operator skill and cuts training time to a minimum. Much less experience is needed to set up new jobs because of the constant arc length feature. Burn-back of the wire to the gun is practically impossible because of the very low open-circuit voltage and the remarkable dynamic characteristics of the welder. An operator can adjust wire feed all the way from maximum down to minimum, where dripping transfer takes place, without the necessity of making any supplementary arc length adjustment on the welder. This would not be possible on any but a rising-characteristic generator.

The basic fact learned in this investigation was that, for a constant arc length, an increase of wire feeding speed resulted in more current and a higher arc voltage. This fact holds true for all the combination of wire and gas investigated.

Further work is in progress on very fine wires and in materials such as magnesium and titanium.

The value of basic study of arc processes is again illustrated in the design of this unique welder which promises to remove the last barriers to the immediate application of a welding process of great potential.

New Development in Fluxes for Automatic Welding and Hard Surfacing

Advantages of mixing properly formulated finely ground particles of flux ingredients together with a proper binder and drying the resultant agglomerate

by L. K. Stringham

THE first step in the development of any automatic welding flux is to define the service for which the flux is intended and what it is supposed to do.

Every man involved in flux development will probably have a slightly different idea as to what a flux is supposed to accomplish. However, probably all of them will include the following factors.

Requirements of a flux:

1. To deposit a weld metal of the desired properties. This may mean chemical or mechanical properties or both.
2. To deposit a weld bead of the desired shape in the joint being welded.
3. To deposit a bead which meets the above requirements at the lowest possible cost.

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Presented at the Thirty-Fourth National Fall Meeting, AWS, held in Cleveland, Ohio, week of October 19–23, 1953.

The earliest submerged arc fluxes were made by mixing finely ground particles of minerals, iron oxide and ferro alloys. Although many miles of successful welds were made with such fluxes, many difficulties in welding were encountered. These included: (1) Raw materials were not uniform; (2) finely ground material did not flow well—it would pack and not properly protect the molten metal; (3) the variation in density of the different ingredients produced segregation in the flux resulting in nonuniform weld metal.

The nonuniformity of the raw materials was brought under control by the proper processing of the raw materials before mixing. However, the fineness and segregation remained a continual difficulty in the use of the submerged-arc process.

The next step in the development of fluxes was to overcome these difficulties of fineness and segregation by the fusion of the mixture prior to its use as a welding flux. After fusion, it was ground to the most desirable particle size.

Through fusion of the mixture, the problems of particle size and segregation were completely overcome.

The fused flux can readily be made uniform chemically; ground to the desired particle size and is completely free of segregation because each particle is exactly the same density as every other particle. Fused fluxes have been applied very successfully in submerged arc welding.

A flux that has been fused and ground is not, however, a cure-all. The fact that it is fused prior to welding results in almost a complete chemical reaction between the ingredients during fusion. Properly formulated fused fluxes do an admirable job of producing the desired shape of bead in the joint being welded. However, since it is almost chemically inert because of the fusion that took place during manufacture, it has very little control over the chemical and mechanical properties of the weld metal. At best just a small percentage of alloy can be picked up by the weld metal from the flux.

Mixing of ferro alloys into a fused flux during fusion is of no help because the ferro alloys oxidize during the fusion process. If the ferro alloys are mixed in the flux after fusion, segregation results as in the early mixed fluxes.

Therefore, if fused flux is used, it is possible to supply only a limited amount of alloy through the use of a solid alloy electrode. Alloy rods have been successfully employed when the alloy content has been low enough, in the case of hardenable steels, to permit the steel to be drawn into a rod.

In order to deposit alloys which cannot be drawn into rod, tubes were made of strip steel and these tubes are filled with metal powder of the proper analysis to produce the desired weld analysis. This is expensive and it is difficult to obtain a uniform weld deposit analysis.

As previously mentioned, another shortcoming of the fused flux is its inability to act as a deoxidizer. The first fused fluxes actually depleted the manganese in the weld metal and it was necessary to use a high manganese wire to prevent manganese depletion. Some later fluxes did act as mild deoxidizers and did increase the manganese content of the weld metal. However, at best, the fused flux is not very effective as a deoxidizer.

In order to overcome some of the shortcomings of fused fluxes, flux development back-tracked to mixed fluxes. Mixed fluxes had the advantage of deoxidizer and alloy additions. If particle size and segregation could be controlled, they would have advantages over fused fluxes.

Therefore, the main problems were: (1) To grind the individual ingredients fine for rapid chemical reaction; (2) to have the flux grains coarse so that the flux would flow well and could be handled easily; (3) To keep the various ingredients from segregating during shipment and use.

All three of these problems would be licked if the individual particles could be mixed together, glued together and then the resulting mixture ground to the desired grain size for welding.

These problems are now licked by agglomeration.

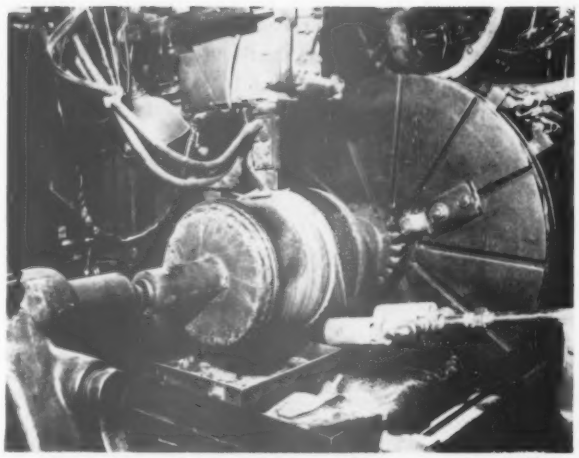

Fig. 1 Setup for building up rolls from a pipe mill

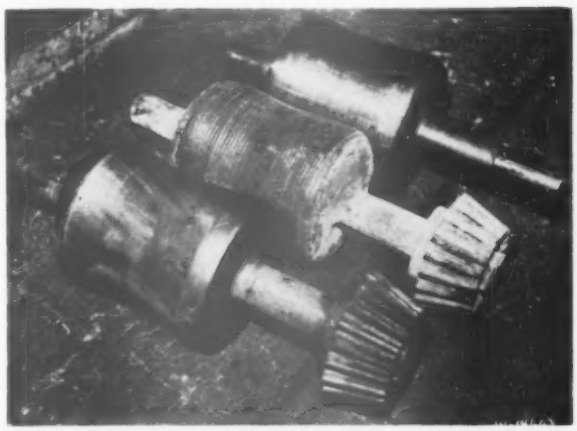

Fig. 2 Worn roll on left, surfaced roll before machining in the middle, surfaced roll after machining on the right

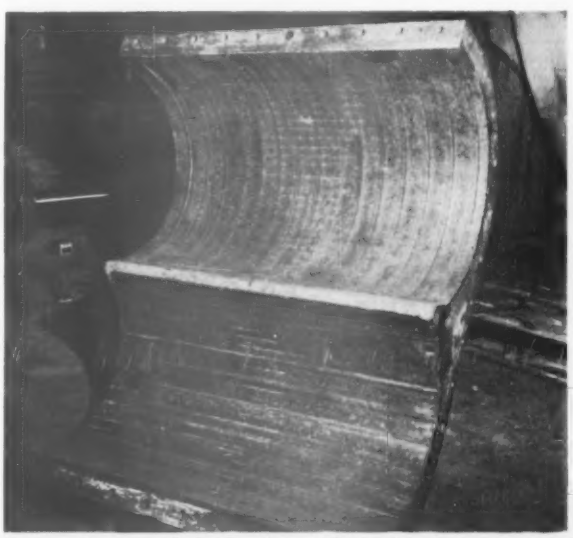

Fig. 3 Bottom of the Banberry Mixer that has been hard surfaced with agglomerated flux. Plates are bent U-shaped after surfacing

Agglomeration is the process of mixing the properly formulated finely ground particles together with a proper binder and drying the resultant agglomerate. The agglomerate is then ground to the desired size for submerged arc welding. Each particle or grain of this agglomerated flux contains hundreds of the finely ground particles tightly held together with the agglomerating agent or binder. Each grain of flux contains the preprocessed minerals and deoxidizers in the proper proportion. Therefore, each grain is chemically like every other grain and they all have the same density. Therefore, there is no segregation. By the agglomerating process of making flux it is therefore possible to include in the flux any minerals, materials, or alloys which can be ground.

An added advantage was also discovered. The density and heat conductivity of the agglomerated flux are lower than that of fused flux. Therefore, less agglomerated than fused flux is melted per foot of weld. This results in lower flux consumption and lower weld cost. By the use of agglomerated flux an entirely new field is open to the users of submerged arc welding, the addition of deoxidizer and alloy in the weld deposit through the flux. An alloy deposit can be made using a mild steel electrode wire.

Agglomerated fluxes to weld mild steel have been available for years and are widely accepted. In that field deoxidizers are added; but, of course, alloys are not. This paper will not discuss these mild steel welding fluxes since they are not new.

A new and rapidly expanding field for agglomerated fluxes is in hard surfacing. In this field mild steel electrodes in conjunction with fluxes containing some or all of the alloys of carbon, chromium, molybdenum and vanadium are most commonly used.

The alloy addition is made to meet the requirements of the job. In one application the requirement will be to deposit the most wear-resistant deposit which can be machined. Two typical examples of this are shafts and rolls which must be machined after welding. In addition to being machinable, these deposits normally must be free of cracks.

Figure 1 shows an installation using mild steel electrode and an agglomerated alloy flux being used to build up rolls from a pipe mill.

Figure 2 shows a worn roll, a surfaced roll before machining and a surfaced roll after machining.

Another application is a deposit which can be hot forged. This deposit can be made more wear resistant than the machinable deposit. However, the forging requirement necessitates a tough crack-free deposit. The plow share is a typical example of applications requiring forging after surfacing. Surfacing is now being applied to some new shares.

Crawler tractor idle rolls is another common application. Exact dimensions are not important. Therefore machining or grinding is classed as an unnecessary expense on this application. However, a smooth and tough deposit is required. Smoothness and uniformity of build-up eliminates the necessity of machining or grinding. Toughness is required to keep it from spalling off in service.

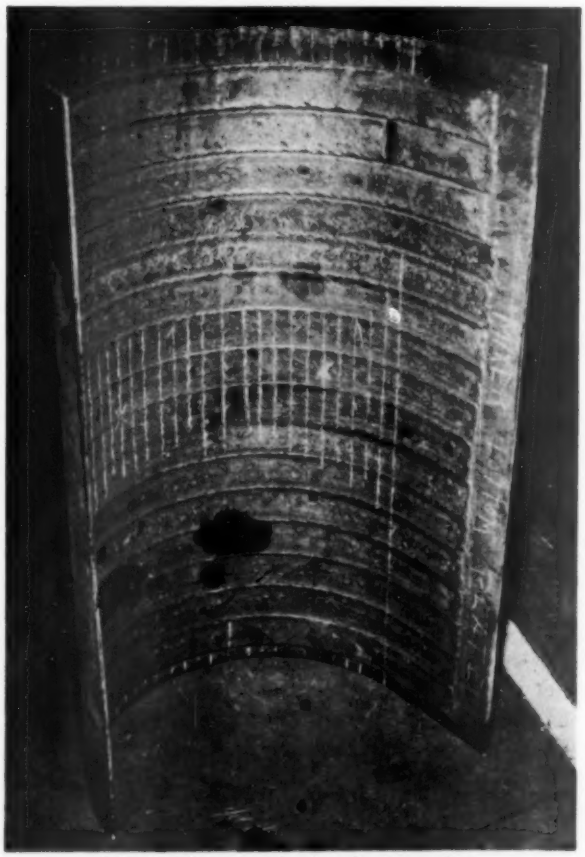

Fig. 4 Close up of mixer bottom plate

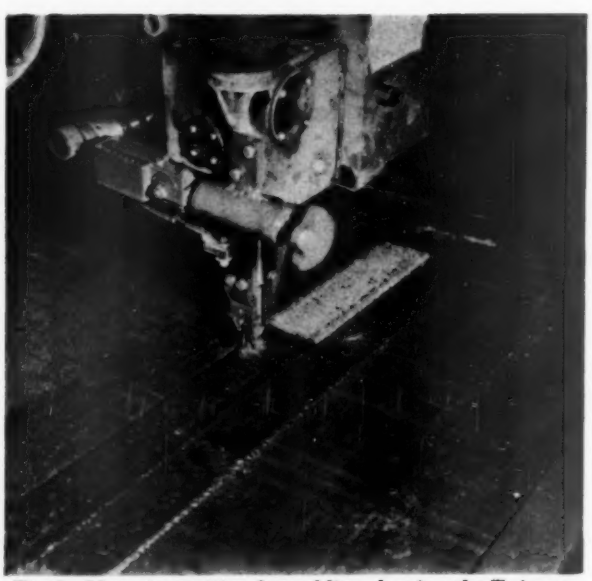

Fig. 5 Plates in position for welding showing the Twinarc-Spreadarc equipment used for depositing hard-surfacing bead with agglomerated flux

A rather unusual application of automatic hard surfacing is the manner in which the bottoms of some large mixers are being surfaced. As can be seen in Fig. 3, the bottom consists of two U-shaped sections. After surfacing these mixer bottoms in several ways, it was found that the most economical way was to surface a flat steel plate of the proper size prior to forming. The entire face of the plate was surfaced with the desired alloy. The plate was then formed to shape in a bend brake to the shape shown in Fig. 4.

In order to surface these plates which were approximately $3^1/_2$ by 4 ft, three concurrent developments were used: The agglomerated flux, the Twinarc and the Spreadarc. I will just briefly point out their function in this application. Figure 5 shows them both in position to surface the plate.

The two wires are fed through the same head at the same speed and are supplied from a common power source. Two wires are superior to one because when placed side by side as in this application, they will produce a wider bead at a higher speed and with less penetration than can be obtained with one arc.

The Spreadarc simply oscillates the two wires back and forth at right angles to the direction of travel. This further increases the width of bead, decreases the penetration, increases the speed and decreases the cost.

The oscillation of the Spreadarc is adjustable to produce an oscillation from 0 to more than 3 in. On this particular application the width of each bead was between 3 and 4 in. Over 3 in. can be obtained when using the Twinarc. It was desirable to deposit the most wear-resistant bead which could be formed without excessive cracking. Since the mixer bottom is not subject to impact during use, some cracking was not harmful.

Figure 6 shows the automatic head with the Twinarc and Spreadarc and the fixture. The fixture was made only rigid enough to keep distortion of the plates from interfering with the surfacing operation. Since the plate was to be formed after welding, no attempt was made to obtain minimum distortion.

Figure 7 shows the finished surface plate prior to forming.

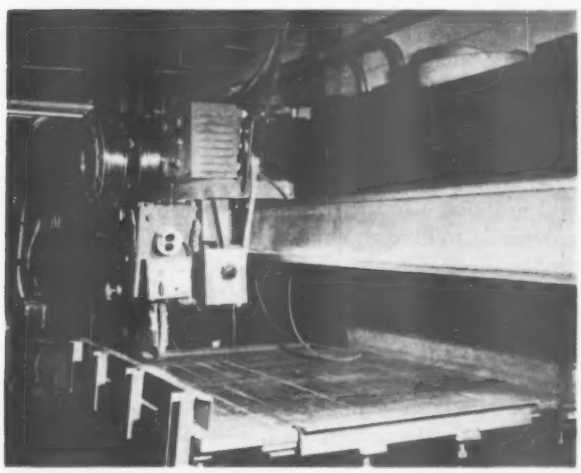

Fig. 6 Shows equipment setup for surfacing plates

Fig. 8 Setup for surfacing scraper blades with agglomerated flux

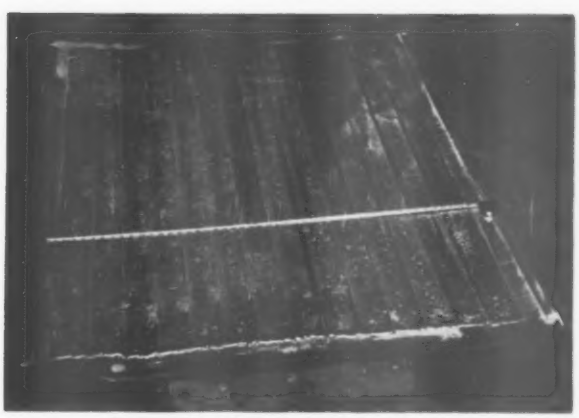

Fig. 7 Finished plate prior to forming

Fig. 9 A pile of finished scraper blades

Fig. 10 A roll of Raymond Bowl Crusher

New scraper blades are now being surfaced with the combination of agglomerated alloy fluxes, Twinarc and Spreadarc.

Figure 8 the setup in the process of surfacing a scraper blade with the combination Twinarc, Spreadarc and agglomerated flux.

Figure 9 a pile of the finished blades. The blades are clamped during welding and the distortion is so little that no straightening is required.

Figure 10 shows the roll of a Raymond Bowl Crusher which has been hard surfaced. In service this is subjected to severe abrasion.

The above are just a few of the applications on which agglomerated surfacing fluxes are being used.

One surprising result being obtained with automatic surfacing with the automatic and agglomerated fluxes is that more wear is being obtained for a given alloy content of the weld deposit than has been obtained from previous deposits. The only apparent reason is the uniformity and smoothness of the deposit. With a uniform analysis and smooth surface there are no weak points at which the wear starts.

This result in the permissible use of a lower alloy content deposit which has the advantage of being tougher, more crack free and lower cost. In addition with the use of a lower alloy it is possible to resurface the part many times. When high alloys are used severe cracking and spalling are frequently encountered when the part is surfaced the second time. When this

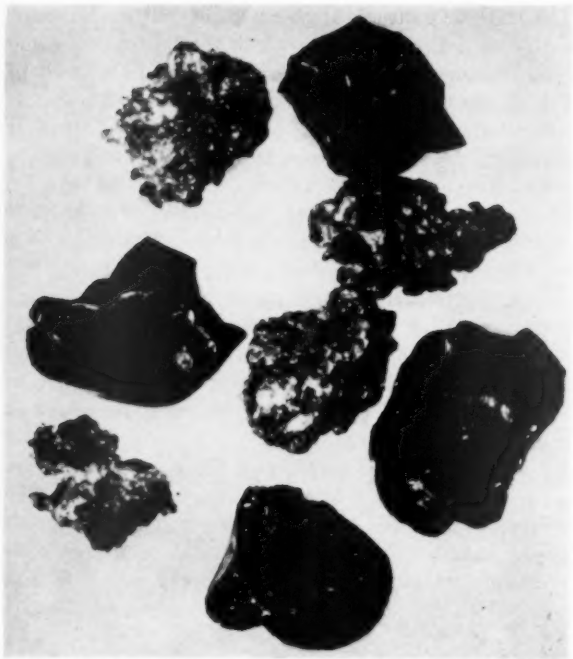

Fig. 11 Comparison of agglomerated and fused fluxes. Black particles are fused, others are agglomerated. Actual size of particles is approximately the size of a pinhead

occurs the part must be scrapped or the expensive operation of removing the remaining surfacing material must be resorted to.

Although the development of agglomerated fluxes is still in its infancy it has already opened new doors to automatic welding. With the use of mild steel electrodes, weld deposits of mild steel, low-alloy, high-tensile and surfacing alloys are being made by the use of agglomerated fluxes.

Where the alloy content is low and can be included in the electrode, it is still normally cheaper to use a mild steel electrode and put the alloy in an agglomerated flux. Where the desired alloy content is so high that it cannot be put into a drawn wire, the use of a mild steel electrode and an agglomerated flux with alloy is cheaper and the deposit is more uniform than can be obtained by other means. For the present, at least, tungsten carbides are not being widely deposited by the submerged arc. Up to the present, these deposits are most successful with the open arc.

However, the surface has just been scratched. In the future, present application will be welded at lower cost, and many new applications will be developed.

Silver Brazing Alloys for Corrosion-Resistant Joints in Stainless Steels

The limitations of silver brazing alloys with respect to Type 430 stainless steels have been discussed

by George H. Sistare, John J. Halbig and L. H. Grenell

Synopsis

Nickel-free silver brazing alloy joints on nickel-containing stainless steels have long been known to have little or no corrosion resistance when subjected to harshly corrosive, saline solutions. Nickel-containing silver brazing alloys were developed to meet these conditions. However, in the case of the nickel-free stainless steels, nickel-free silver brazing alloy joints are not resistant to mildly corrosive media, such as humid air or flowing tap water; even the conventional nickel-containing silver brazing alloy joint is not completely resistant. Evidently, a corrosion-resistant bond on nickel-free stainless steel depends upon the deposition of a nickel-rich layer from the brazing alloy over the entire area covered by the brazing alloy. Very few of the feasible nickel-containing silver alloys investigated can produce a complete deposit of this sort; but at least one type has been developed that will. The separation process appears to be a form of crevice corrosion that results from imperfections at the edge of the brazing alloy fillet. This in turn stems from oxygen-concentration cell activity in the presence of moisture.

INTRODUCTION

ABOUT a quarter of a century ago, when silver brazing alloys were just beginning to be used as they are today and stainless steel was a relatively new metal, it was thought that galvanic corrosion might be a troublesome factor in silver alloy brazed steel and stainless steel assemblies. Yet, a series of tests produced no evidence of galvanic corrosion, and the percentage of corrosion failures in innumerable silver brazed units of all types has since proved to be infinitesimally small. Two kinds of corrosion were encountered. The first was the failure of the bond between nickel-free silver brazing alloys and nickel-containing stainless steel in severe chloride corrosion; the second was the dissolving of the silver brazing alloy from all types of stainless steel joints during the passivating of brazed assemblies with nitric acid. For the first, there was a simple and satisfactory remedy: the use of nickel-containing silver brazing alloys. For the second, the remedy is to passivate *before*, not after, brazing.

The shortage of nickel and the general substitution of nickel-free stainless steels for the nickel-containing alloys have complicated the brazing situation enormously. Thus, the bond between a nickel-free silver brazing alloy and a nickel-free stainless steel may fail in a few days in innocuous corrosion media, such as humid air or running tap water. Furthermore, the bond between a typical nickel-containing silver brazing alloy and a nickel-free stainless steel undergoes some peripheral corrosion in the same media. True, this is not likely to be destructive, but it is unsightly. It also can be exaggerated by brazing techniques which enhance the liquating tendencies of silver brazing alloys of this type.

During the last two years, it has been demonstrated that a completely corrosion-resistant bond between a silver brazing alloy and a nickel-free stainless steel depends on the deposition of a fairly uniform layer of nickel-rich constituent from the brazing alloy over the entire surface of the stainless steel covered by the brazing alloy. This nickel-rich constituent alloys with the stainless steel during the brazing cycle and forms a corrosion-resistant, nickel-rich interface between the brazing alloy and the stainless steel. The problem has been to develop a silver-brazing alloy that can produce such an interface and, at the same time, can make a sound joint at a reasonably low temperature.

In seeking a solution to the problem the three laboratories of the respective authors have cooperated in investigating practically all of the factors which might or might not have been expected to affect the corrosion resistance of the bond. But, most of these—surface condition of the stainless steel before brazing, fluxes used, type of joint, brazing technique, and treatment of the joints following brazing—were insignificant or impractical. The search finally narrowed down to a quest for the particular type of silver brazing alloy required to do the job. Therefore, this report will deal mainly with the nature of silver brazing alloys and the nature of the silver brazing alloy bond on stainless steel.

George H. Sistare is Research Metallurgist, Handy & Harman, Bridgeport, Conn.; **John J. Halbig** is Research Engineer, Armco Steel Corp., Middletown, Ohio, and **L. H. Grenell** is Head of the Metallurgical Section (Engineering Division), Frigidaire Division, General Motors Corp., Dayton, Ohio.

Presented at the National Fall Meeting, AWS, held in Cleveland, Ohio, week of Oct. 19–23 (1953).

THE NATURE OF SILVER BRAZING ALLOYS

All silver brazing alloys may be considered to fall into one of three categories:

Type 100—Alpha, and/or, Alpha-Beta, Copper-Base Alloys.
Type 200—Eutectiferous, Copper-Silver Base Alloys.
Type 300—Alpha, and/or, Alpha-Beta, Silver-Base Alloys.

The three types are amply illustrated by the 40 compositions listed in the Tabular Survey, which includes the flow point of the alloys together with a brief description of their fluidity and the corrosion resistance of their joints on nickel-free stainless steel. So far as possible, the general discussion that follows will be in terms of types rather than specific compositions. Furthermore, it will be largely confined to a description of the results obtained with practical brazing techniques.

The alpha, and/or, alpha-beta, copper-base alloys (Type 100) examined include alpha, and/or, alpha-beta, copper-zinc alloys, an alpha-beta, copper-tin-zinc alloy (Tobin Bronze) and alpha-beta, copper-silver-zinc alloys. These solid solution alloys are all fluid on stainless steels and the high temperature (1600° to

Tabular Survey

No.	*Composition, %*							*Flow point, °F*	*Fluidity on "430"*	*Corrosion resistance on "430"*
	Ag	*Cu*	*Cd*	*Mn*	*Sn*	*Zn*	*Ni*			
Alpha, and/or, alpha-beta type, copper-base alloys										
110c	..	60	..	..	..	40	..	1655	Good	OK
113a	..	47	..	..	..	42	11	(1700)	Good	OK
120a	9	53	..	..	..	38	..	1565	Good	(?)
c	30	38	..	..	..	32	..	1410	Good	NG
123a	40	26	..	..	..	32	2	1350	Good	NG
Eutectiferous type, copper-silver base alloys										
210a	72	28	..	..	..	..	..	1435	Very poor	NG
213a	70.6	27.4	..	..	..	..	2	(1480)	Poor*	NG
220a	61	34	..	5	..	..	..	1410	Good	NG
c	46	39	..	15	..	..	..	(1370)	Good	NG
223a	65	28	..	5	..	..	2	(1445)	Good	OK (?)
c	50	36	..	6	..	..	8	(1600)	Fair*	OK
230a	60	30	..	..	10	..	..	1325	Poor	NG
233b	63	28.5	..	..	6	..	2.5	(1475)	Poor	OK
g	60	28	..	..	10	..	2	(1400)	Poor	OK
240a	25	52.5	..	..	..	22.5	..	1575	Good*	NG
c	45	30	..	..	..	25	..	1370	Good*	NG
d	60	25	..	..	..	15	..	1325	Good	NG
243a	40	30	..	..	..	28	2	1435	Good*	OK (?)
b	40	30	..	..	..	25	5	1560	Fair	OK (?)
e	65.1	27.9	..	..	..	5	2	1420	Poor	(?)
g	61.6	26.4	..	..	..	10	2	1375	Fair	NG
h	60	16	..	..	..	22	2	1280	Good	NG
250a	35	26	18	..	..	21	..	1295	Good*	NG
b	50	15.5	18	..	..	16.5	..	1175	Good	NG
c	45	15	24	..	..	16	..	1145	Good	NG
253a	50	15.5	16	..	..	15.5	3	1270	Good*	OK (?)
b	50	13	13	..	..	21	3	1205	Good	(?)
260a	57.3	32.7	..	3	7	..	..	1345	Good	NG
263a	43	37	..	15	3	..	2	(1475)	Good	OK
270a	54	18	..	5	..	23	..	1285	Good	NG
273a	52.5	17.5	..	5	..	23	2	(1350)	Excellent	NG
280a	56	22	..	..	5	17	..	1205	Good	NG
283a	62.5	27.5	..	..	2.7	5.3	2	1390	Poor	(?)
b	57	23	..	..	3	15	2	(1325)	Good	NG
Alpha, and/or, alpha-beta type, silver-base alloys										
320a	85	..	..	15	..	..	..	1760	Good	OK (?)
330b	75	..	..	..	..	25	..	1345	Good	NG
333c	74	..	..	..	..	25	1	(1355)	Good	NG
d	73	..	..	..	..	25	2	(1375)	Good	NG
e	70	..	..	..	..	25	5	(1425)	Fair*	(?)
353b	75	..	..	..	3	20	2	(1400)	Good	(?)

NOTES:

The flow point figures within parentheses indicate approximate values.

The asterisk in connection with the fluidity denotes a strong tendency toward liquation.

The 40 brazing alloys listed represent about 40% of the total number of alloys that were investigated. In classifying their joints on Type 430 as "NG," "(?)," "OK (?)" and "OK," the following procedure was generally employed: (1) Spreading test bonds of the type illustrated were considered to be "NG," if

(*a*) The bond failed in 5 to 10 days in flowing tap water.
(*b*) The 5- to 10-day crevice was of the type that would fail on longer exposures.
(*c*) Extreme measures such as prolonged heating during brazing were not distinctly beneficial and did not (in the case of the nickel-containing alloys) result in a suitable nickel-rich deposit.

(2) Similar joints were classified as "(?)," if they were ordinarily "NG," but were susceptible to improvement by prolonged heating at elevated temperatures. From a practical point of view, a joint of this sort is as objectionable as a joint of the first type. (3) The "OK (?)" bonds were those which underwent partial corrosion, but did not fail, when brazed in a conventional manner. Considerable attention was devoted to joints of this kind in order to determine the effect of brazing variations upon their corrosion resistance. A requirement for slow brazing at high temperatures is almost as objectionable, practically speaking, as extensive corrosion following quick brazing at low temperatures. (4) An "OK" signifies that no corrosion took place except for very limited peripheral attack following very quick brazing at very low temperatures.

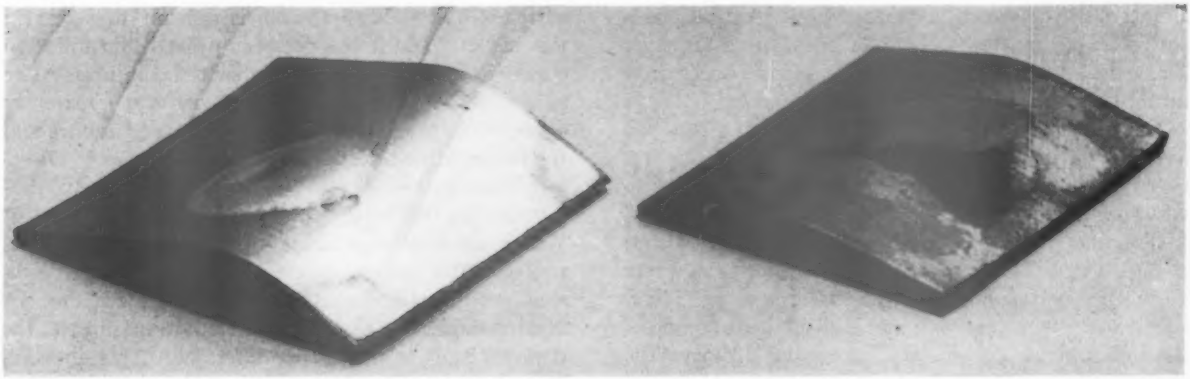

Fig. 1 1- x 1-in. Type 430 specimens. (Left) Bent after brazing; (right) bent after exposure

1700° F) alloys, which contain no silver *and* no nickel, form completely corrosion-resistant bonds on nickel-free stainless steel. Substitution of silver for copper, however, gradually destroys the corrosion resistance of the bond. The rate at which it does so is roughly proportional to the amount of silver involved. Silver-free alloys have melting temperatures too high for many practical applications.

The eutectiferous copper-silver base alloys (Type 200) listed in the Tabular Survey are but a small part of the large number of copper-silver base alloys that retain the essential features of the basic, eutectic system. However, they include representative samples of most of the common silver brazing alloys together with a considerable number of selected experimental compositions. Since *none* of the nickel-free alloys form corrosion-resistant bonds on nickel-free stainless steel, the list of nickel-free compositions is a fairly complete roster of bad examples.

Cadmium, manganese, tin and/or zinc do have some influence on the rate of corrosion of the basic copper-silver bond on nickel-free stainless steel. In general, the rate of corrosion is roughly proportional to the quantity of these elements present, alone or in combination: yet percent for percent the rate increases as cadmium is replaced by tin, tin by manganese and manganese by zinc. This, as it happens, is about the same order in which the four elements stand in relation to increasing the wetting of the basic copper-silver alloys on stainless steels. Curiously enough, the amount of silver present in relation to the amount of copper in the eutectiferous range appears to have no definite effect upon the corrosion rate. This is a marked departure from the way in which silver accelerates the corrosion of the alpha-beta alloys (Type 100).

Among the alpha and/or alpha-beta, silver-base alloys (Type 300) examined were three alpha alloys (aluminum-silver, manganese-silver and silver-zinc) plus a number of alpha-beta alloys (silver-zinc, copper-silver-zinc and silver-tin-zinc). Of these solid solutions, only the aluminum-silver (5% Al: Flow Point 1560° F) formed a completely corrosion-resistant bond. The manganese-silver bond underwent partial corrosion and the alpha-beta bonds all failed. The cost, flow temperature and drossiness of the silver-aluminum alloy disqualify it as a general purpose solution.

The role of nickel in these alloys (the three basic types) is elusive, since it is a remedy whose efficiency varies from 0 to 100%. To illustrate the point, the nickel in the nickel-containing alloys in the Tabular Survey may be considered to be completely ineffective, partially effective or completely effective:

Completely ineffective:
- Ag-Cu-Zn: Ni (123a)
- Ag-Cu: Ni (213a)
- Ag-Cu-Zn: Ni (243e, g and h)
- Ag-Cd-Cu-Zn: Ni (253b)
- Ag-Cu-Mn-Zn: Ni (273a)
- Ag-Cu-Sn-Zn: Ni (283a and b)
- Ag-Zn: Ni (333c, d and e)
- Ag-Sn-Zn: Ni (353b)

Partially effective:
- Ag-Cu-Mn: Ni (223a)
- Ag-Cu-Zn: Ni (243a and b)
- Ag-Cd-Cu-Zn: Ni (253a)

Completely effective:
- Ag-Cu-Mn: Ni (223c)
- Ag-Cu-Sn: Ni (233b and g)
- Ag-Cu-Mn-Sn: Ni (263a)

The reasons for the erratic behavior of nickel are not fully understood, but apparently they derive from variations in the form in which the nickel is present in the brazing alloy; and from variations in the ease with which the nickel in the brazing alloy can migrate to, and alloy with, the nickel-free stainless steel. From this point of view, a nickel-rich constituent is to be preferred to one in which the nickel is highly diluted. The richer it is the better it will behave. This is the reason why 243b joints corrode less than 243a joints and it is one of the reasons why 233b and 233g joints are almost immune to corrosion.

Another factor that plays a vital part in the performance of the *nickel-containing alloys* relates to the amount of nickel available in the usual very thin edges of a silver brazing alloy fillet. This is simply a question of the amount of nickel available in a given amount of brazing alloy, but it is complicated by the fact that

almost all the brazing alloys having nickel-rich constituents of the right sort liquate during brazing. Thus, the alloy that runs out to the edges is deficient in nickel because it has run away from the nickel. Alloys 233b and 233g which do not flow anywhere near as well as most silver brazing alloys, and do not form thin edges, probably owe a large part of their immunity to corrosion to their poor fluidity.

Odds and Ends. A certain number of odds and ends should be put into the record. One additional silver alloy, the germanium-silver eutectic, was tried and found wanting. So were minor additions of aluminum, lithium and phosphorus to conventional Type 200 alloys. Zinc and 95-5 tin-antimony soft-soldered joints did not corrode.

THE NATURE OF THE SILVER BRAZING ALLOY BOND ON STAINLESS STEEL

Except for their extremely limited resistance to corrosion in the presence of moisture, the nickel-free stainless steel joints formed by nickel-free silver brazing alloys are equal in every respect to those formed by the best of the nickel-containing alloys. They have the same strength in tension and shear, the same adherence on bending and the same resistance to tearing (on chiseling the alloy off the steel or on tearing the joint apart). Furthermore, there is no evidence that a "crevice" such as is shown in Figs. 3 and 5 exists before removal of the flux with hot water and the copper-plating of the specimen. Moreover, if a submicroscopic crevice or imperfection is present at the edge of a nickel-free fillet, it is entirely probable that a similar defect exists at the edge of a nickel-containing fillet.

When a silver brazing alloy which does not produce a nickel-rich deposit is applied to a ferritic stainless steel in the usual manner, quickly and just above its flow point, very little diffusion occurs and the joint corrodes. The diffusion zone is difficult to detect in this instance and it has not been proved that diffusion occurs in longer periods at higher temperatures. The fact is, however, that the corrosion rate apparently decreases in proportion to the time at temperature and the temperature interval above the flow point. Therefore, the corrosion rate is probably inversely proportional to the depth of the diffusion zone.

This method of reducing the corrosion rate is impractical and there is no evidence, to date, that corrosion can actually be eliminated in this manner. A much simpler and more reliable alternative is the deposition of a nickel-rich interface. This involves migration in addition to diffusion and it is somewhat surprising that it takes place as fast as it does. A good nickel-containing alloy will function as it is supposed to in anything except a *very short* brazing cycle.

A series of seven plates was prepared to illustrate the character of the bond obtained with typical nickel-free and nickel-containing silver brazing alloys. Figure 1 shows two standard corrosion specimens (Alloy 250c), one of which was bent before and the other bent after corrosion. Figures 2, 4 and 6 reveal the typical structure of the bond area at the center of the fillet on similar specimens (Alloys 250c, 253a and 233g) and Figs. 3, 5 and 7 show the structure at or near the edge (Alloys 250b, 253a and 233b). The nickel-rich deposit may be clearly observed in Figs. 4, 6 and 7 but is absent, or nearly so, in Fig. 5. The part of 253a shown in Fig. 5 is actually the part that has liquated or run away from the part left behind in Fig. 4.

DETAILS

Nickel-Free Stainless Steels Investigated

Type 430 stainless steel was actually used for most of the tests, but check runs on Types 403, 410, 430Ti and

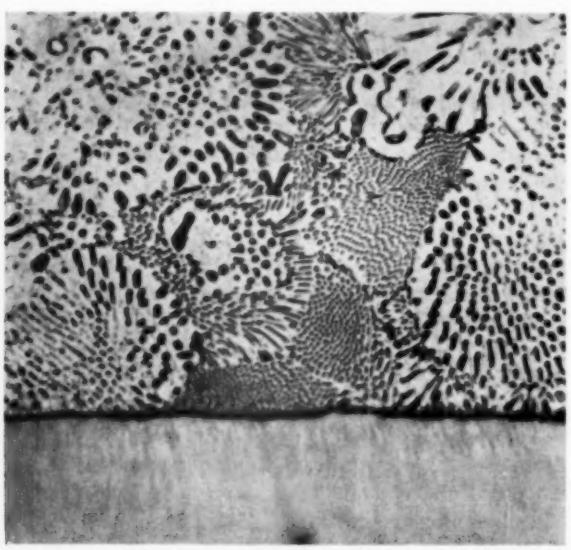

Fig. 2 Cross section of an alloy 250c fillet on Type 430 stainless steel at a location toward the center of the fillet

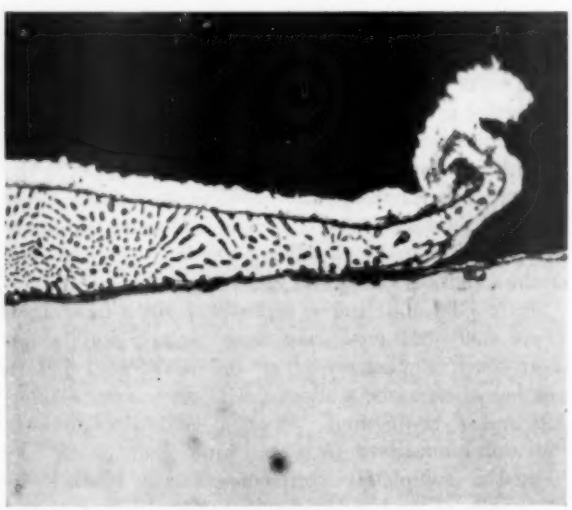

Fig. 3 Edge of an alloy 250b fillet after washing in tap water and copper-plating to aid micro preparation

446 stainless steels indicated that all straight chromium steels are vulnerable.

Besides the Type 430 joints, quite a large number of Type 430-to-copper specimens were examined because this combination of metals is of special interest to the refrigeration industry. In general, the presence of the copper did not seem to have any definite effect on the corrosion of the Type 430 bond.

Preparation of the Stainless Steel Prior to Brazing

Two aspects were considered, the nature of the surface of the Type 430 and the effect of copper and nickel plate on a Type 430-to-copper assembly. The nature of the surface did not appear to have any effect upon the results because rolled, ground and pickled surfaces behaved in exactly the same manner.

In plating experiment (*a*) copper was plated on the Type 430 component, in (*b*) nickel was plated on the copper, in (*c*) nickel was plated on the Type 430 and in (*d*) nickel was plated on both components. The results were inconclusive, since (*a*), (*b*) and (*d*) corroded but (*c*) did not. It seems likely, however, that an adherent heavy nickel plate on the Type 430 might be effective.

Fluxes Used in Brazing

A considerable number of commercial fluxes were used together with a number of experimental varieties. With the exception of the fluxes to which nickel powder and nickel fluoride were added in an attempt to deposit nickel from the flux, none of the fluxes had any effect upon the results. Moreover, the nickel-bearing fluxes were of so little benefit that they were abandoned soon after they were first investigated.

Types of Joints

Experimental spreading test specimens (see Fig. 1) and butt seam joints were used in addition to typical laboratory size, tee, lap and flanged joints. The spreading test specimen, often used to evaluate the fluidity of brazing alloys, was extremely useful, since it exaggerates the spreading of a brazing alloy. Therefore, it enhances the corrosion tendencies and makes an excellent corrosion detector.

Brazing Techniques

Most of the specimens were torch brazed, although many were furnace brazed in air and in hydrogen. The brazing alloys were first applied in the usual manner at temperatures 25 to 50° F above their flow points. Then, the rate of heating was varied to exaggerate liquation (slow heating) or to minimize it (fast heating). Finally, extended brazing periods and higher brazing temperatures were investigated in an attempt to improve the alloying characteristics of the brazing alloys which did not deposit a nickel-rich interface. The results have been discussed in the preceding sections.

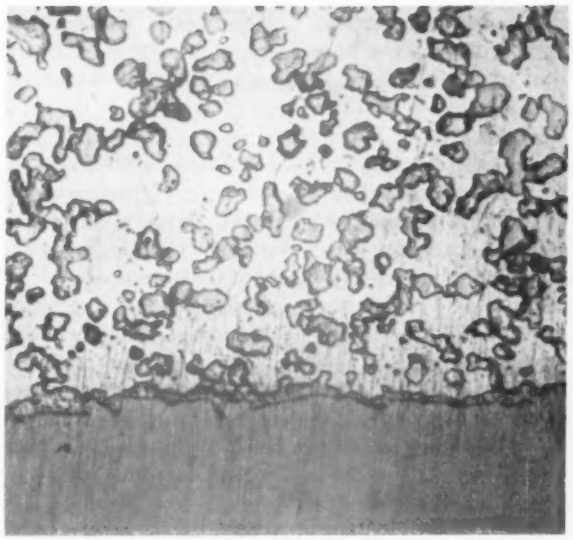

Fig. 4 Center of an alloy 253a fillet on Type 430 stainless steel showing the presence of a nickel-rich deposit at the interface

Treatment of the Joints Following Brazing

Stress relieving, grinding or sandblasting, electropolishing, electroplating and soft solder flushing (95Sn – 5Sb) were among the factors investigated. Of these, only the last, the soft solder coating, was at all effective. However, removing the vulnerable edges of a joint with a nickel-bearing brazing alloy, such as 253a, does eliminate peripheral corrosion.

Corrosion Testing

A humid atmosphere, running tap water, a stagnant 4% NaCl solution and a 5% (NaCl) salt spray were used in the early stages. Later, after the corrosive character of running tap water had been thoroughly demonstrated, it became the accepted standard; it is

Fig. 5 Edge of an alloy 253a fillet after washing in tap water and copper-plating to aid in micro preparation. Note the absence of an appreciable nickel-rich deposit

more corrosive than a humid atmosphere. Exploratory tests usually ran five days, but specimens that survived the five-day test have been run as long as a year or more.

The first sign of corrosion in running tap water is the appearance of one or more red rust spots at the edges of the brazing alloy. This may occur in a few minutes or a few days. Subsquently, as the corrosion proceeds, the spots grow into a rust segment which may or may not enclose the entire periphery of the brazing alloy. If the bond is completely destroyed thereafter, the brazing alloy and the stainless steel may part company in the tap water. If it is not, owing to insufficient time or because the bond is one that does not corrode completely, the extent of the corrosion can be evaluated at any given time by merely bending the stainless steel away from the brazing alloy and observing to what extent the fillet lifts off the stainless steel.

THEORY OF FAILURES

The destruction of the bond and the accompanying slight corrosion of the nickel-free stainless steel under the silver brazing alloy, when the stainless steel is not coated with nickel from the brazing alloy cannot be explained in a simple manner. If galvanic corrosion were the cause, visible etching or pitting should occur on the surface of one of the dissimilar metals near the interface, and, outside the joint. This does not take place. Instead, the joint separates due to action at and beneath the interface. Moreover, if galvanic corrosion were responsible, it would be reasonable to assume that joints made of carbon steel would certainly be affected. Yet steel joints were found to be sound after exposure to flowing tap water for more than a year, this despite the fact that the steel was a mass of rust outside the joint area.

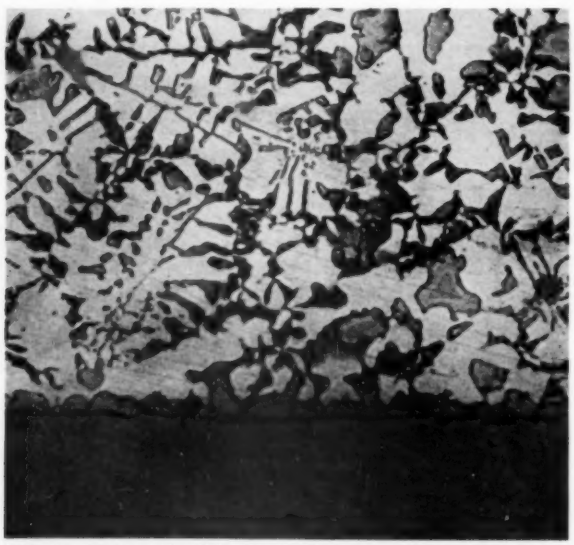

Fig. 6 Center of a fillet typical of alloy 233g on Type 430 stainless steel showing the presence of a nickel-rich constituent at the interface

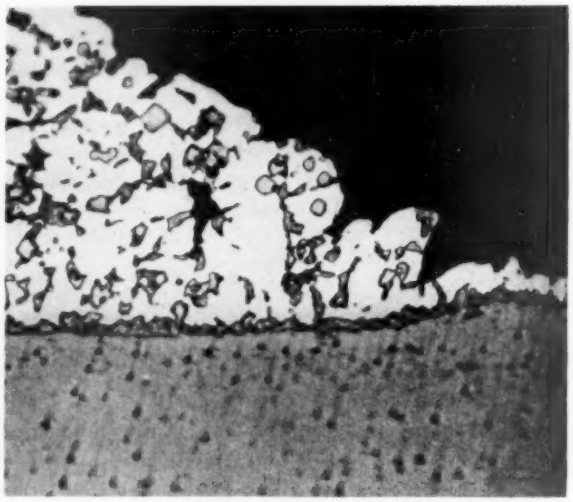

Fig. 7 Edge of an alloy 233b fillet showing the presence of a nickel-rich deposit at the edge

The manner in which the joints corrode in such media as flowing tap water points to the phenomenon of crevice corrosion. In this instance, however, the only crevices available are the minute imperfections at the outer edge of the brazing alloy. In addition, imperfections of this sort are bound to be present in all fillet edges, including the edges which *do not corrode* as well as those which do.

The mechanism of the crevice corrosion process might be described in this manner. If the area under an imperfection is depleted of oxygen, becoming anodic, the infinitely greater area outside is relatively oxygen-rich and cathodic. This means that an oxygen-concentration cell could be set up. Once this cell began to function, the stainless steel on the inside would be in an active condition, whereas the metal on the outside would be passive. Then the oxygen concentration differential and the potential between the active and passive stainless steel might provide the energy needed for the growth of a crevice from an imperfection. Under these conditions any iron going into solution within the crevice would be present in the form of ferrous ions, which are soluble. As these ions migrate to the mouth of the crevice, ferric hydroxide would be formed, which would then precipitate as red rust.

This hypothesis may have its weaknesses, but it describes the phenomena accompanying the separation of joints very aptly. The first evidence of corrosion is usually the appearance of one or more rust spots around the periphery of a fillet. These develop into rust segments that may join up with other segments or may develop independently. The presence of a nickel-rich interface seems to inhibit the progress of an expanding crevice, for joints made with silver brazing alloys that provide a nickel-rich interface over most of the area covered have withstood running tap water for more than a year. This appears to be so even though a rusted crevice existed at their edges inside of a few days.

CONCLUSIONS

If at times this report seems to be an attempt to describe the behavior of a tray full of fleas, the resemblance is apt. After all, the fundamental purpose of a brazing alloy is to make a joint. When the brazing alloy must flush one of the joined members with a particular constituent while the joint is being made, its joining characteristics are apt to suffer from it.

Two silver brazing alloys have been developed which, so far, make joints on nickel-free stainless steel completely resistant to tap water corrosion. They are relatively high temperature alloys and are much less fluid than conventional silver brazing alloys. Still, joints can be made with them and the 1475–1500° F alloy (233b) can be supplied as strip or wire. The 1400–1425° F alloy (233g) is only available in powder form.

Present alternatives to the two special alloys just described are three standard alloys: 243b (flow point 1560° F), 253a (flow point 1270° F) and 243a (flow point 1430° F). Joints made with these alloys will corrode to some degree, but the depth of the corrosion penetration may be decreased by avoiding liquation, extremely short brazing cycles and underheating. Furthermore, 243b joints will corrode less than 253a joints, and 253a joints less than 243a joints.

Two other methods are to nickel plate the stainless before brazing (not fully investigated) or to soft-solder-flush the joints after brazing (proved).

ACKNOWLEDGMENTS

The authors wish to acknowledge the technical assistance provided by F. A. Petrie of Handy and Harman; A. E. Taylor and J. C. Wilkins of the Armco Research Laboratories; and H. A. Towner of the Frigidaire Division, General Motors Corp.

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EDITORIAL PREVIEWS

New Foster Wheeler Plant Starts Limited Operations

FOSTER Wheeler Corp., manufacturers of heavy equipment for steam power plants, oil refineries and process industries, has begun limited operations at a new plant in the rapidly growing industrial region of Mountaintop, Pa., 9 miles south of Wilkes-Barre, it was announced recently by Earle W. Mills, President. Due to the need for training new personnel, full operation of the plant did not occur until Jan. 1, 1954.

Equipped with the most modern fabricating tools, the five million dollar plant will turn out pressure vessels of varying proportions, including some of the largest and heaviest in demand. Part of an eight million dollar expansion and retooling program begun three years ago, the new plant will also help to relieve heavy manufacturing schedules at the corporation's other plants in Carteret, N. J., Dansville, N. Y., and St. Catharines, Ontario, Canada.

Among its major tools will be an 8000-ton hydraulic beam press weighing over three million pounds and said to have an effectiveness in bending steel plate—hot or cold—seldom before equaled. Largest of its type yet made, the press is capable of bending plate 8 in. thick, and (in the case of lighter plate) 40 ft long into half-shells which, when welded together, will form pressure vessels of the unusual proportions required for the higher pressures demanded by various industries. It was built by Baldwin-Lima-Hamilton of Philadelphia, Pa.

Another outstanding tool will be a 2,000,000-v Van de Graaff X-ray generator capable of penetrating steel 12 in. thick. The machine will photograph weld metal with unprecedented clarity of detail, exposing any minute flaws that may occur in the metal. Using fewer and shorter exposures, it will perform its work in considerably less time than conventional X-ray equipment.

Manufactured by High Voltage Engineering Corp. of Cambridge, Mass., the generator was originally developed for cancer research, and later adapted for industrial use. It was put to its first practical test by the U. S. Navy during World War II to determine construction details of enemy ordnance.

To guard against the possibility of escaping rays from the powerful machine, it will be housed in a fortress-like structure, with walls of reinforced concrete 4 ft thick, and removed 550 ft from the main plant.

Other special tools that will make up the new plant, although basically similar to many used in other steel fabricating plants, are unique in their capacity to perform monumental operations, or in their ability to perform familiar tasks automatically, and more efficiently. Among these are:

1. A new system of automatic shielded-arc welding whereby vessels up to 8 in. thick and 12 ft in diameter may be welded at speeds considerably greater than in single-wire welding.

2. A plate-handling device that positions, accurately and without appreciable loss of metal temperatures, the huge slabs of preheated steel that will be formed in the beam press.

3. A series of mobile, high-speed radial drills that may be stationed anywhere along a 230-ft stretch of raised track. The drums to be drilled may be placed on either or both sides of the drill platform. The arrangement makes possible the use in combination of as many as six drills on a single cylinder. (Considering that the length of drilling time required in special operations may represent up to 25% of total fabrication time, it is apparent that a drill arrangement such as this one would result in a substantial lowering of drilling time, and also permit better utilization of the tools, regardless of the size of vessels to be processed.)

The plant stands on a 130-acre tract at the crest of a mountain in the Wyoming Valley, an industrial region favored by good rail transportation, proximity to steel and other materials sources and an availability, for the present time, of skilled labor. The area was recently hard hit by male unemployment due to the closing of some of its coal mines. However, this situation has improved recently, as new industries have moved into the Valley. When in full operation, the Foster Wheeler plant is expected to employ around 500 men.

Among the products to be fabricated are such varied equipment as heat exchangers for nuclear power; sections of oil towers and pressure vessels weighing over 100 tons, and equipment for jet engine regenerators,

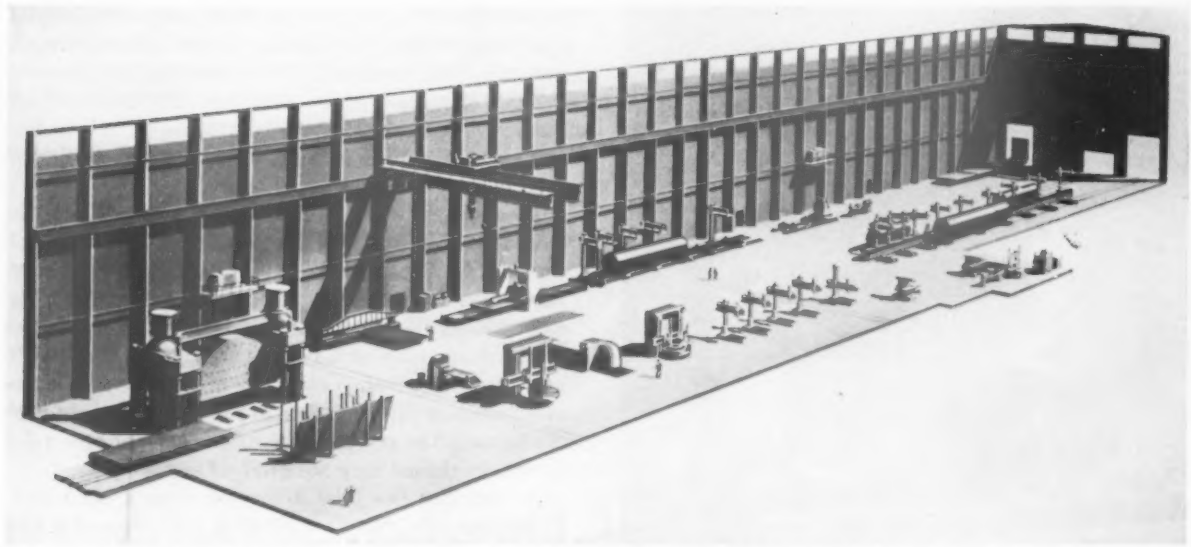


Fig. 1. Artist's view of interior of the new five million dollar Foster Wheeler plant at Mountaintop, Pa., showing many of the unique machines that will process pressure vessels of unusual proportions

Shown in this drawing (left to right, back row) are: an 8000-ton beam press, plate edge planer, overhead cranes, double housing planer, automatic welding machines, and drum facing machine. In the foreground (left to right) are: a 500-ton crimping press, 144-in. vertical boring mill, pinch-type bending rolls and high-speed radial drills.

some of the latter weighing as much as 140 tons.

PROCESSING A TYPICAL 125-TON PRESSURE VESSEL

Steel is delivered to the plant by rail from the steel mill in sets of four plates, 28 ft 3 in. x 9 ft 6 in. x $4^3/_4$ in. thick, which are stored in racks opposite the beam press. The first step in the processing is to preheat the plates in a normalizing furnace, where temperatures as high as 2100° F are available. Several plates can easily be placed in the furnace, which has inside dimensions of $45^1/_2$ ft x 16 ft x $7^1/_2$ ft high. A flat car lined with firebrick, and designed to carry a 200-ton load, is run into the furnace. After heating, the plates are carried to the beam press, where they are lifted from the car by an overhead crane and placed on the dies.

A built-in plate-handling device positions the hot steel easily and accurately, so that there is a minimum loss of metal temperature and accuracy to within a fraction of an inch. The huge press then exerts its 8000 tons of pressure to form a half cylinder of the steel plate.

After the four plates are formed into half cylinders, they are moved into the shot blast room immediately adjacent to the beam press. Two of these units can be accommodated at the same time on the 50-ton car. In this room the shells are subjected to a blast of metallic particles which knock off all scale formed by the heating and pressing operation. The metallic particles (similar to "bee-bee" shot) are recovered for use at a later time, after being cleaned in the dust collection equipment.

The half cylinders are then moved to a bed planer for machining welding grooves along both edges of the half shells. Another tool of unusually large proportions, the bed planer has a table travel area of 44 ft, over-all bed length of 92 ft and width (between housing ends) of $122^1/_2$ in. When the planing is complete, the four shell sections are then assembled to form two cylinders, each 72 in. ID and 28 ft 3 in. long. This assembly is accomplished by tack welding and by attaching a backing strip under each welding groove. Test plates are then attached to each cylinder, and welded at the same time as the long seams. These test plates are later subjected to a series of severe tests.

The two cylinders are then moved to the automatic welding machines, where submerged arc d-c current and automatic flux recovery welders traveling along a 150-ft track deposit weld metal in the long seams. When the grooves have been filled with weld metal, the backing strip is removed and the inside seams are chipped and welded, to make a perfect union of the metal in the sections of plate.

The cylinders are then moved to the drum-end facing machine, where a similar type of welding groove is machined into each circular end of the cylinder. This drum-end facing machine has a 98-in. diam swing facing head. The horizontal movement of the facing head is 24 in., although only about 4 in. is required in the operation. The dished heads, delivered by the steel mill in this size, are then ready to be assembled to the cylinders. (For a normal sized vessel, the dished head would be formed in one of the other of Foster Wheeler's plants; however, because of the size and weight of this particular drum, it would not be practical to install the machinery necessary for such an operation.)

Since the original vessel was designed for 56 ft 6 in. in length, two cylinders of the type described above are joined, and heads are attached at both ends after removal of the test plates. The vessel now must be

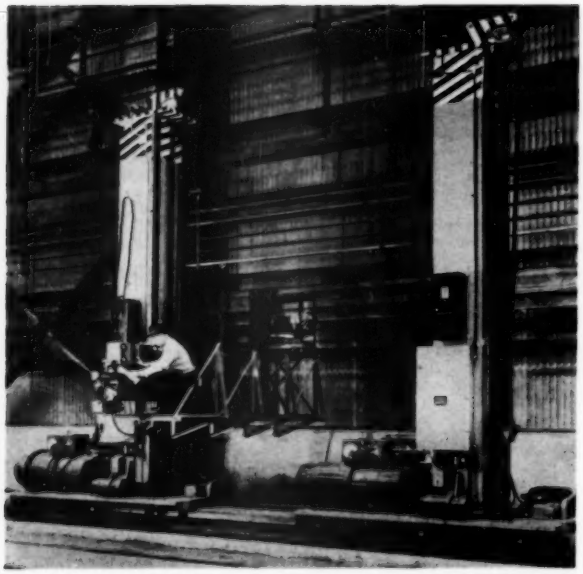


Fig. 2 Twin-arc welding machines are capable of welding 8-in.-thick plate at speeds considerably faster than in single-wire welding units

These direct-current twin arc welders are mounted on specially designed platforms which travel longitudinally on a 150-ft long track, and which may be raised or lowered to accommodate pressure vessels up to 12 ft in diameter.

returned to the automatic welder for welding of the circular seams, several of which can be welded at the same time. The drum is revolved on power-driven rolls at the exact speed required by the high-speed welding machines.

Laying out and installing nozzles, bosses and welding connections is hand operation. Specialized burning equipment is used for burning out such openings, while highly skilled layout men fit and adjust connections and tack weld them into place. Hand welders then proceed by conventional methods to weld them in place.

The drum is now ready for X-ray examination, to make certain that every part of the weld is perfect. The drum is loaded on a 200-ton flat car and drawn into the X-ray building.

In the film development and inspection rooms, located outside the 4-ft concrete walls, the X-ray result is speedily determined. Should any flaws appear in the X-ray, the defective weld metal would be chipped out and the drum rewelded, after which a second X-ray picture would be taken.

The drum is then ready for stress relieving. In the welding operation certain stresses and strains have been set up in the metal formation by the extreme heat generated in the welding process. The vessel is loaded on the 200-ton capacity car and hauled into the furnace. The 80 propane gas burners in the $83^1/_2$-ft long stress-relieving furnace are lighted and the vessel is subjected to heat of approximately 1200° F for a period of 5 hr. After this heat treatment, the drum is allowed to cool slowly. It is then returned to the main building for hydrostatic test. All nozzle openings and heads are closed and water is pumped into the drum until a pressure equal to one and one half times the ultimate operating pressure is achieved. In this case the design pressure of the drum is 1550 psi, thus the test pressure is 2323 psi. The vessel is then carefully inspected for leakage. Upon satisfactory completion of the hydrostatic test, the drum is ready for layout and drilling of tube holes.

Approximately three hundred 3-in. holes are required in this drum. The radial drills reserved for this task are located on a raised platform 230 ft long. Eight of these high-speed drills are mobile and may be moved along the platform for wider utilization. These drills are mounted on a 19-in. diam column and an 8-ft arm extends over the center line of the drum. Drums may be set up on either side of the raised platform and can be turned by power-driven rolls. After all tube holes have been drilled they are grooved so that tubes when expanded into the tube holes will form a tight seal. Drums are now ready for painting and shipping. The 150-ton crane, or, if the drum should be larger, it—in tandem with the 50-ton crane—can easily lift the vessel and place it in a gondola-type freight car for shipment.

AUTOMATIC SHIELDED TWIN-ARC WELDING

The new automatic-shielded-welding process installed at the new Mountaintop, Pa., plant of Foster Wheeler Corp., was built to specifications by the Cecil Peck Co. of Cleveland and Lincoln Electric Co. These automatic welding machines are power driven and can be raised or lowered to accommodate vessels up to 12 ft in diameter. The entire assembly in each unit travels on a track 150 ft long. The units are type LAF, automatic flux recovery, power-driven booms which are controlled at the operator's station. These automatic welders are capable of welding plate 8 in. thick at speeds considerably faster than single-wire welders.

Essentially, the process operates in the following manner: Granular flux is deposited on the joint to be welded, deeply enough to cover the completed weld.

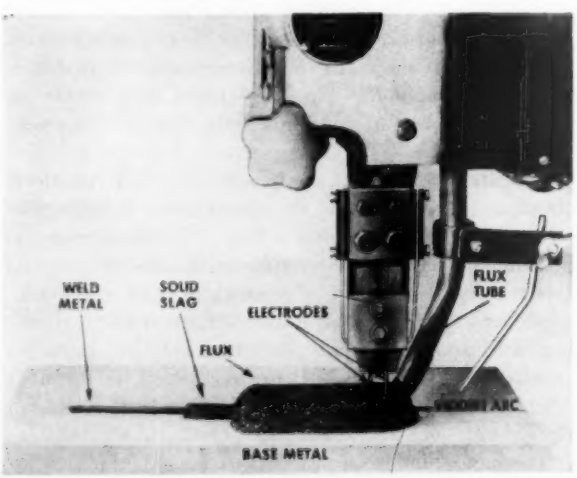


Fig. 3 Closeup of one of the Lincoln Electric Automatic Shielded Twin-Arc Welding Units

Bare metallic welding electrodes in tandem are power fed into the blanket of flux at rates of feed controlled automatically for proper arc length. Direct current produces the hidden arc between the electrodes and the joint. The resultant arc heat fuses electrodes and parent metal, producing the weld. Flux adjacent to the arc melts, floats on the surface of the molten metal, then solidifies as a slag on top of the weld. Since the arc and molten metal are blanketed by flux at all times, the weld metal is completely protected from contact with the air, assuring maximum quality of welds and making possible the use of extremely high amperage for faster welding and lower costs.

While there is little difference in quality of weld obtained between alternating current and direct current welding, the direct current system was chosen because of the unique Foster Wheeler arrangement whereby the entire welding unit travels over the length of the 150-ft track. Being lighter, the d-c unit has the advantage of eliminating bulky transformers, which would have to travel with the welder along the track.

Contact with power source is obtained by a hidden track below the floor similar to the third rail used for electric trains. Power consumed by one of the welding units is approximately 50 kw.

In the case of welding circular seams, the portable welding machine is held in one position and the drum revolved by means of power rolls.

In addition to the automatic machines shown, portable welding machines, both dc and ac, are used.

A Modern Electrode Plant—Lancaster, Pa.

A MANUFACTURING plant so immaculate that even its 41,000 sq ft floor surface is fully vacuum-cleaned every 24 hr has other cleanliness features which make it fit like a glove in this heartland of the tidy Pennsylvania Dutch.

Construction and equipment details which make it the most modern plant existing for its purpose either bar dust and dirt from entering or chase it out of the new Eastern Welding Electrode Plant of A. O. Smith Corp. near Lancaster, Pa.

In spending a million dollars to build and equip the plant, the Milwaukee steel fabricating firm has a major purpose—to create ideal conditions for the "perfect" manufacture of welding electrodes.

Perfectly uniform electrodes—which are desirable in obtaining stable and uniform welds—can be turned out one after the other under hygienic laboratory conditions. The trick is to mass-produce the electrodes by the millions under factory conditions.

For example, if a small piece of dirt or extraneous material becomes lodged in the extrusion press which squeezes out the rods, it will cause imperfections which will affect the performance of that whole rod batch.

With rods going through the extrusion press at a rate of 20 per second (twice as fast as the firing rate of a machine gun) it should be apparent that a lot of damage can be done in a very short time.

Along with its study of optimum manufacturing conditions in its new plant, A. O. Smith's Welding Products Division sought to produce also the best possible conditions of plant safety, comfort and efficiency and the lowest maintenance costs.

The result is a plant which went into operation recently with these unique features:

Interior walls of glazed tile which eliminate maintenance.

None of the materials on the building's exterior needs paint or other care.

A building with no windows or skylights, to better control the ingress of air both from a standpoint of quantity and location.

A system of air pressure balancing under which slightly more outside air will be automatically admitted than is exhausted from that portion of the building walled off to contain the dry mixing operations.

The slight internal pressure thus created will tend to confine dust and dirt to those precincts and bar it from finishing stages of manufacture.

Incoming air is filtered to remove all possible contamination from it—this despite the rural location of the plant. Such air as is exhausted is passed through a wet type rotoclone and washed to remove any possible dust. This adds to the insurance that all outside air will be pure before admitted to the plant.

Fig. 1 This is the exterior front view of A. O. Smith Corp.'s Eastern Welding Electrode plant containing 41,000 sq ft of space near Lancaster, Pa.

Fig. 2 Meticulous weighing and measuring of materials going into the manufacture of electrode coating at Lancaster plant is part of the high uniform quality attained

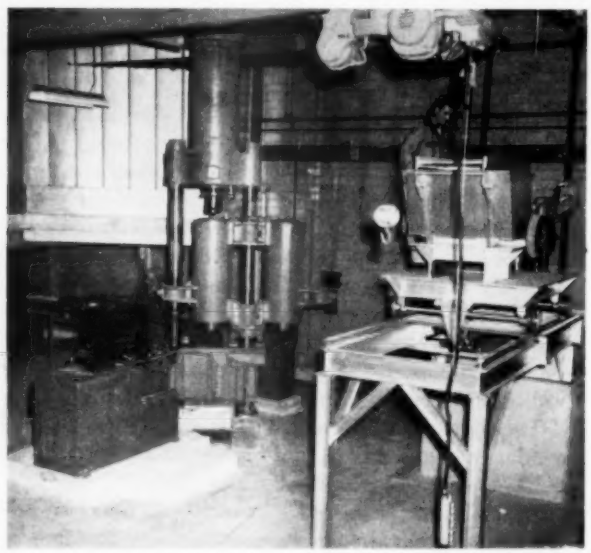


Fig. 3 Operator in background is feeding the slug press which forms long clay-like molds of electrode coating material from the wet mix. These slugs then are fed into the extrusion press (cylinders at left) which forms the coating on the rods at the rate of 20 per sec, then feeds the coated rods into the baking oven

Further contributing to cleanliness in the plant, propane gas is used for both the baking oven and for heating the building.

Every effort is bent to insuring the uniformity of materials, both as to weight, mixture and application in the manufacture of welding electrodes in the new A. O. Smith plant.

Because even a slight absorption of moisture by the dry mix can disturb the accuracy of the formula for the

Fig. 4 In the baking process electrodes move the length of this 150-ft modern baking oven three times. Six control zones and a complex control system regulate variables such as air distribution, zone humidity and zone temperatures. As can be seen, multiple door openings make every part of the baking process accessible for frequent visual inspection and for quick clearance of oven jams.

coating applied to the wire, the silicates used are stored underground at constant year-round temperature of 55° F. And an air-conditioned room in which hygroscopic materials are stored insures the unvarying amount of moisture in these materials and consequent uniformity of mixes.

All these mechanical features to insure maximum perfection in production of electrodes are backed up by a statistical quality control program designed to spot flaws in production almost as quickly as they begin to occur. This control program guards the integrity and uniformity of the electrodes right to the consumer's door.

Decision to locate the new plant at Lancaster was based on several factors. One of these was the strained capacity of the Milwaukee A. O. Smith plant to produce electrodes in the quantity required to meet the sharp increases in sales—increases much sharper than the industry as a whole since World War II ended.

And once the need of a new plant was apparent, it was economically advisable that it should be located within close distribution distance of the eastern and southeastern markets for electrodes. The eastern metalworking market alone comprises about one-third of the potential electrode business.

Tubular Elements Simplify Fabrication and Lower Costs of Radar Screens

RADAR scanning screens for naval vessels are mounted high in the ship's superstructure. This imposes severe requirements for light weight, yet demands great strength to resist the winds, vibrations and pitching and tossing movements that occur in this high and exposed position. Also, though large, these screens must be accurately shaped and must retain this shape to preserve the operating characteristics of the radar.

To achieve all this, engineers of ITE Circuit Breaker Co. departed from the usual design approach of forming the screen's supporting frame entirely of girder sections. Instead they formed the frame of vertical ribs, but connected these by tubular spanning members across the top and bottom, as shown in the accompanying illustration of the finished screen (Fig. 1).

By consultation with the technical staff of Superior Tube Co., of Norristown, Pa., the ITE engineers learned that a standard product of Superior—stainless steel tubing-type AISI 304—was available with the required strength and lightness to form the top and bottom spanning members of the parabolic frame. They adopted this tubing in the 1.0-in. OD size for the top spanning member and the 0.50-in. size for the lower edge of the radar screen frame. By taking advantage of the bending and welding properties of this tubing,

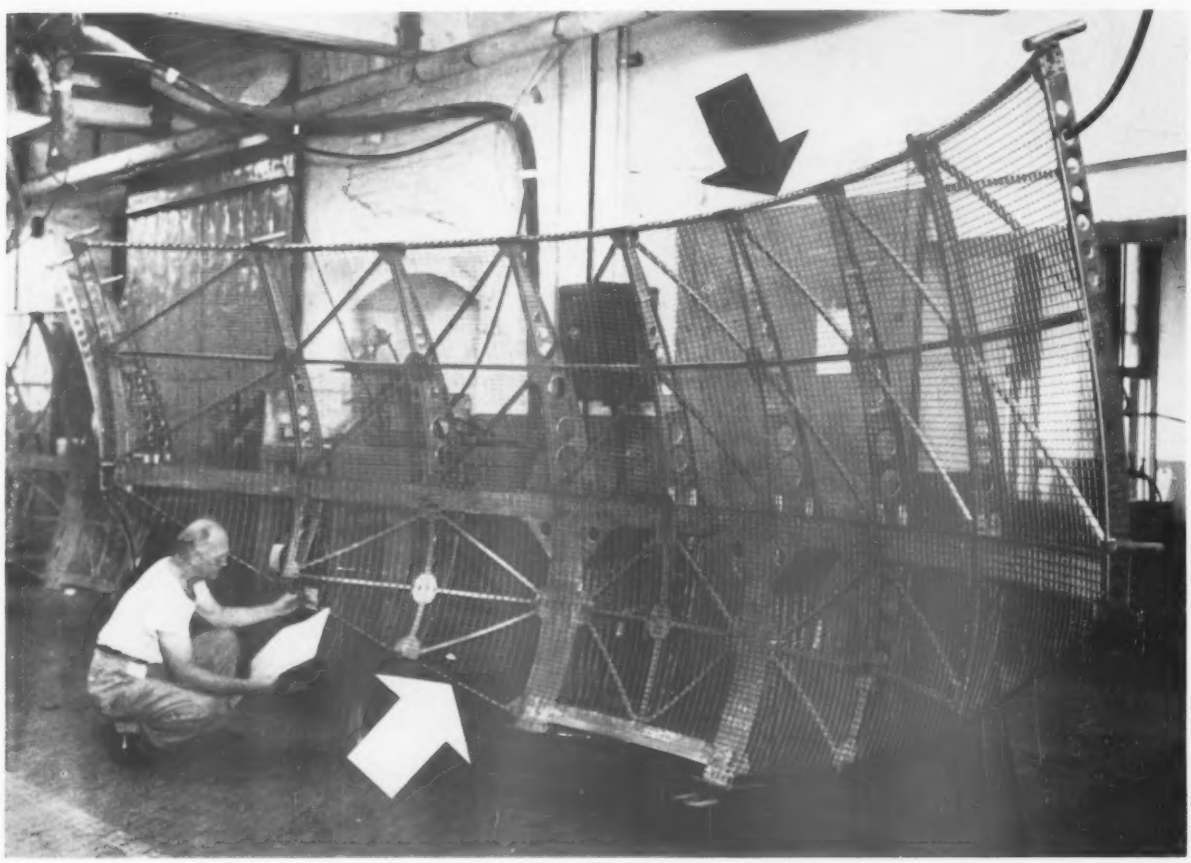


Figure 1

ITE engineers developed a simple fabricating procedure. Net result of this new structural design and new fabricating technique is a radar screen of the required lightness, strength and shape, but produced faster, at lower cost, with less use of skilled labor and with less consumption of strategic materials than were formerly needed.

A step-by-step explanation of this new fabricating procedure is given in the following series of illustrations.

Figure 1 shows the finished radar screen, destined for mounting on the scanning mast of a ship at sea, getting final meticulous inspection for conformity with Navy's rigid manufacturing specifications. Note the unusual structural design using tubular spanning members (arrows) forming the top and bottom edges of the parabolic screen. The tubing's light weight, structural strength and ease of fabrication (by cold forming and shot welding) speed assembly time and cut product costs.

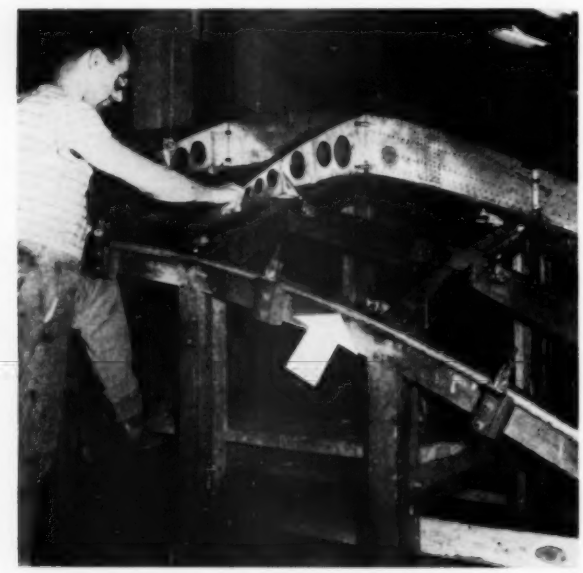


Figure 2

Step 1 (Fig. 2): Since both edges of the radar screen are parabolic, ITE engineers experimented with methods of tube bending which would avoid the usual mandrel techniques. They came up with the surprisingly simple solution of attaining the desired curve by hand bending the long top edge tubing sections to conformity with a template. Three men accomplish the shaping of these sections without using mandrels inside the tubing—and without creating distortions in tubing cross section.

The upper half of the screen's skeleton is built on a wooden shaping form. After the single length of tubing which forms the top edge of the screen is shaped by hand to a template, it is clamped in place on the upper-half assembly frame (see arrow). Vertical ribs are also clamped in place on the form, then ribs and tube are

Figure 3

welded together. Cantilever action of the assembled tubing adds considerable rigidity to the skeleton.

ITE engineers and metallurgists next tackled the problem of joining the tubing to stainless vertical ribs of the screen assembly on a mass production basis, and mastered the technique of electric shot welding for speed and bonding strength.

Step 2(Fig. 3): Tubing ends are plug welded to corner braces, electric shot welded to vertical ribs. Bracing provides the extra joint strength necessary for tube rigidity.

Step 3 (Fig. 4): The shorter $^1/_2$-in. tubing lengths presented a more difficult problem. However, by arranging three special shaping rolls as shown in this figure, the tubing is brought to the required parabolic shape by giving it several passes through this "shaper."

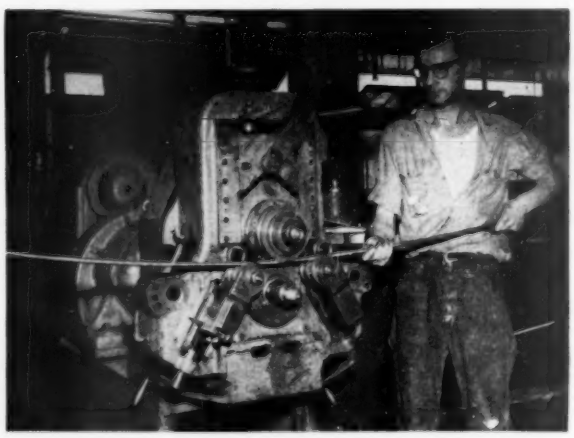


Figure 4

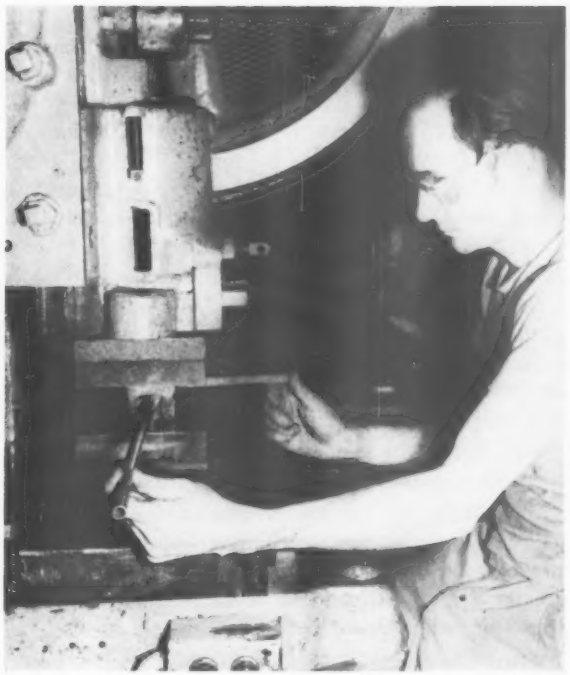


Figure 5

The $^1/_2$-in. AISI 304 stainless tubing, cut to the right lengths, is passed through the cold rolls without a mandrel. Each time the tube passes between rollers, the degree of arc is increased. The gentle pressure of the rolls will not distort tube cross-sectional roundness even when this forming pressure is continued. In repeated tests, ITE engineers have formed sample sections of Superior tubing in 360-deg circles without creating significant stresses in the tube.

Step 4 (Fig. 5): After the lower-edge tubing has been shaped to the right curvature, a hydraulic press flattens the structural tubing for easy joining to radar screen rib ends. Rapid and uniform pressure of the press insures a perfectly flat joining surface at the precise point of contact without: (1) affecting the tube's parabolic shape, (2) distorting the cross sections along spans where rigidity is specified or (3) unduly stressing the metal at flattened areas.

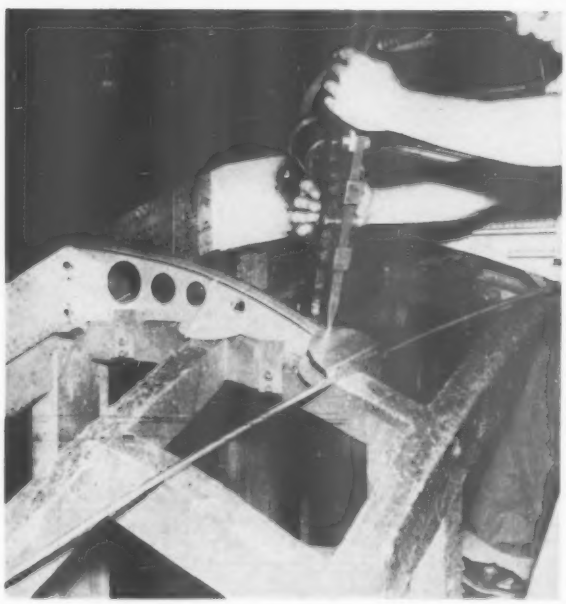


Figure 6

Figure 7

Figure 8

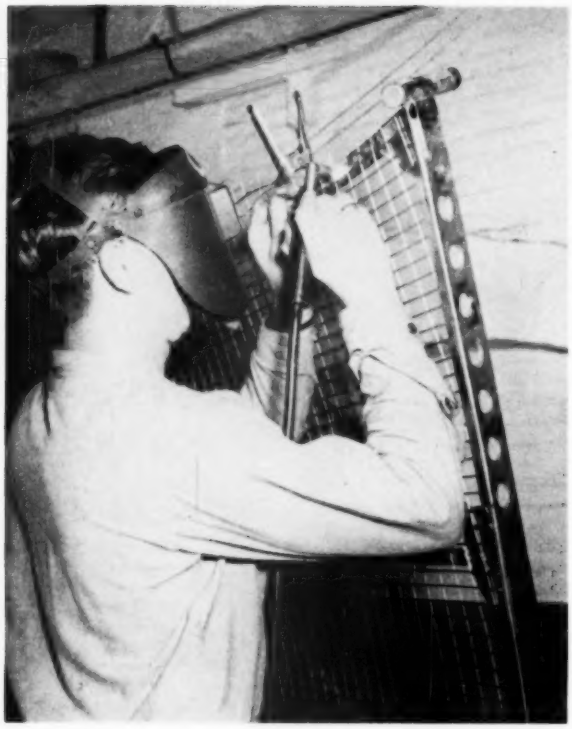


Figure 9

Step 5 (Fig. 6): Half-inch preshaped Superior tubing structural support members are electric shot welded to stainless joint flanges, which in turn are shot welded to the bottom ends of radar screen vertical ribs. Assembly of ITE's radar screen rigid skeleton is done on specially constructed wooden forms. Welders reach spots to be tacked with electric hand welding machines which are suspended from ceiling on track carriages. This ITE procedure greatly simplifies the heretofor difficult techniques involved in welding radar screens.

Steps 6 (Fig. 7): Final joining of $^1/_2$-in. tube members to the radar screen frame is accomplished by shot welding of the tacked joints. Lower assembly of the screen skeleton has been removed from wood-shaping form, is now ready to be joined to upper assembly.

Step 7 (Fig. 8): Stainless steel wire screening is shot welded to the assembled radar screen frame.

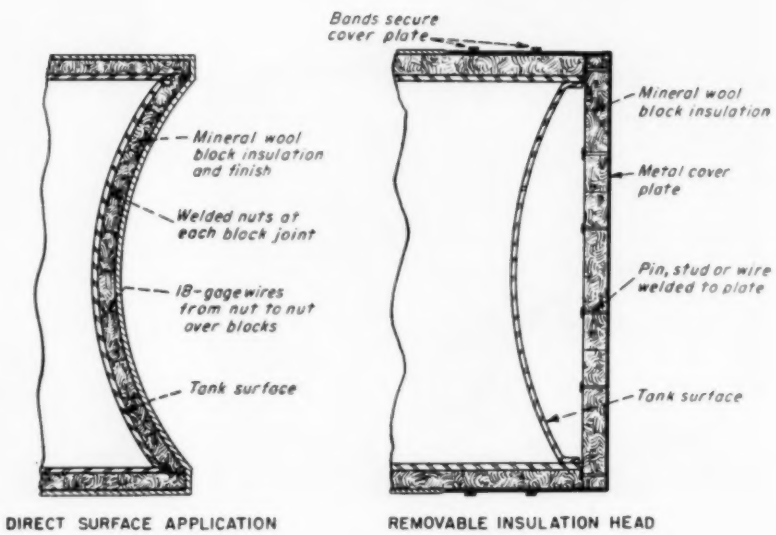
Step 8 (Fig. 9): Top and bottom edges are welded on face of screen. Excess screening is clipped 1 in. beyond tubing, rolled over and tacked along reverse side. For greater structural strength along the edges of the parabolic radar screen, inert arc welding is used.

Step 9: Inspection of finished screen. See Fig. 1.

Concave Tank Ends Are Easy Insulating Jobs with Welded Anchors

SECURING insulation to concave ends of heated horizontal tanks is not a simple matter of banding as with convex ends and cylindrical tank surfaces. Each section of mineral wool block insulation on a concave surface must be individually held in position. As shown on the left in the drawing, an effective method of attachment on concave tank ends employs nuts welded to the surface as anchors for tie wires passing from nut to nut over each section of insulation. The alternative removable-head construction on the right is useful on tanks where the concave ends cannot be welded or where periodic internal inspection of the tank is simplified by easy removal and replacement of the insulation.

Welded edgewise to the metal surface, $^1/_4$-in. nuts are spaced between each horizontal row of block insulation so that at least two vertical rows of nuts cross each insulating section. For example, applica-


Bands secure cover plate
Mineral wool block insulation and finish
Welded nuts at each block joint
18-gage wires from nut to nut over blocks
Tank surface
Mineral wool block insulation
Metal cover plate
Pin, stud or wire welded to plate
Tank surface
DIRECT SURFACE APPLICATION
REMOVABLE INSULATION HEAD

tion of 6 × 18-in. mineral wool block insulation requires welded nuts at 6-in. vertical intervals and not less than 9-in. horizontal intervals. The 18-gage tie wires are passed through the nuts and tightened over each section of insulation as it is placed in position. The final step is the application of appropriate finishing materials such as mineral wool insulating and finishing cements, followed by a waterproof coating as specified. The same installation steps apply to the use of welded rods and studs as well as to nuts.

The removable head is constructed by first attaching mineral wool blocks to a metal cover plate of the proper diameter. The insulating blocks are impaled on pins, studs or wires welded to the cover plate at regular intervals. Special clips are placed over the pins and studs or the welded wires are bent over to hold the insulation tightly in place. Sheet metal is then cut and welded onto the cover plate to form its cylindrical sides. The cover plate is fitted over the end and held by bands around the tank. The additional cost of the removable head over surface application is partly offset because there is no need for finishing the insulation.

"A" Frame Gets an *A* in Welding Problem

GIVE a railroad welding engineer a tough problem and you will see a contented man. Some of the toughest welding jobs have a habit of coming his way, and soon the trouble is in the past. Here is a fine example of how engineers on the Chicago & Eastern R.R. licked a tough one in preparation for a car-building program at the railroad's Danville, Ill., shops.

Welding angle irons to web plates in fabricating the two side and two center sills of a 70-ton fish-belly flat car by the submerged melt process looking like an involved affair. Since the bottom contour of the sills changes direction four times, a mechanized welding unit was required that could move longitudinally and diagonally at the same time.

Through joint effort, engineers of the C&EI and Oxweld Railroad Service Co. installed a "Unionmelt" DS welding head on a specially designed mechanized "A" frame carriage. This 4-ft high carriage straddles the work in gantry fashion and rides on two 60-ft long rails, as shown in Fig. 1. Two other rails upon which the "Unionmelt" machine travels are mounted atop and crosswide to the "A" frame. The "A" frame is equipped with a 1-hp., 1750-rpm, d-c motor and a series of rheostats which furnish variable longitudinal speeds of 20 to 48 ipm. Shaft connections to a drive wheel

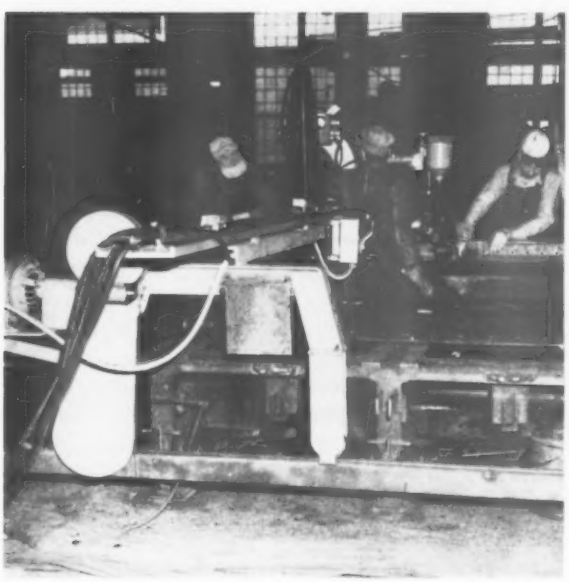


Fig. 1 Starting the "A" Frame on its way to welding floor angles to a web plate in the fabrication of side sills for fish-bellied flat cars at a Chicago and Eastern Illinois Railroad Shop. The mechanized frame straddles the work, riding on 60-ft rails, and carries a "Unionmelt" welding machine on its beam

Fig. 2 Changing contour of fish-bellied side sill is easily followed by "toeing-in" the guide wheel on the welding head. Here the guide wheel is automatically adjusting direction during welding of bottom angle irons to a side sill

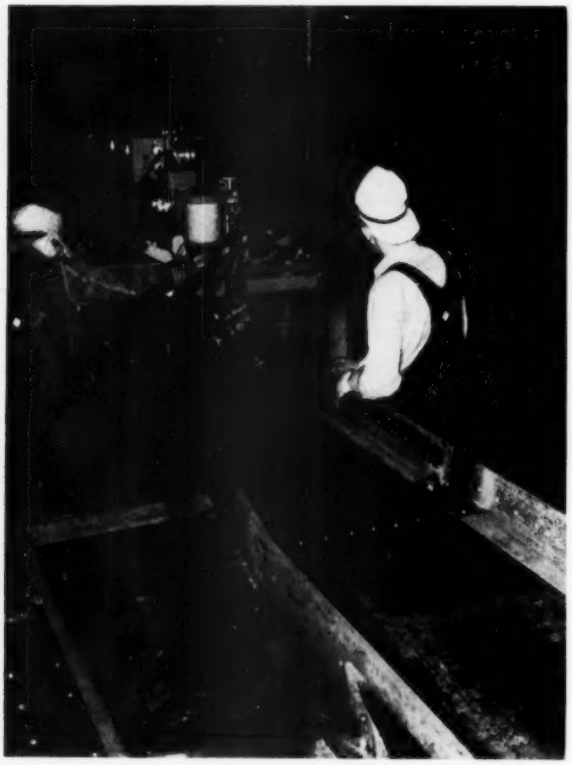


Fig. 3 Floor angles are welded to the opposite side of a side sill by simply changing the angle of the welding head, as shown. Spacer plates are placed in the 5-in. gaps between floor angles to permit uninterrupted welding

Fig. 4 Welds joining the top and bottom angles are clean and smooth, requiring no finishing

on both sides of the gantry propel it along the main rails. A clutch permits disengagement for manual pushing of the carriage.

Fabrication of the side sill is begun by welding a 6- x 4- x $^3/_4$-in. angle iron to the top length of a 52-ft long, $^3/_8$-in. thick web plate. This will be the inside floor angle of the side sill. After the angle is clamped and tack welded into position, the "A" frame is moved directly over the assembly. The type DS-37 carriage riding crosswise on the frame is locked in place and the welding head cocked at a 45-deg angle. This $^5/_{16}$-in. fillet weld is perfectly straight, so only the "A" frame is set in motion longitudinally. Welding speed for this operation is 24 ipm at 780 amp, d-c reverse polarity. The welding rod used is Type No. 36, $^5/_{16}$ in. with a 90-grade melt. Web plate and angle are open-hearth mild steel.

It is in the next operation that the "A" frame best proves its versatility and worth. Five lengths of angle iron are clamped, then tack welded to the bottom of the web plate, following the fish-belly contour. The welding head guide wheel is set to "toe-in" about $^1/_4$ in. to follow the contour of the angle irons. As the weld angle changes, the guide wheel automatically adjusts the direction of welding. This variation in direction is evident in Fig. 2. There is no loss in welding speed.

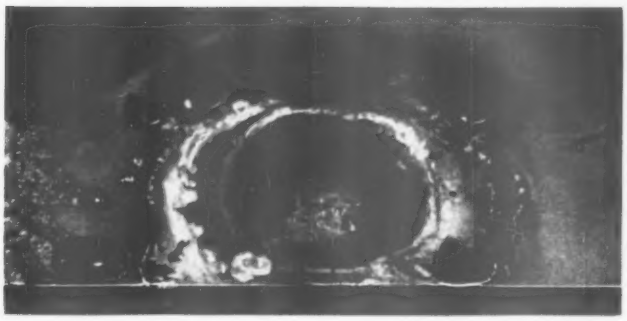
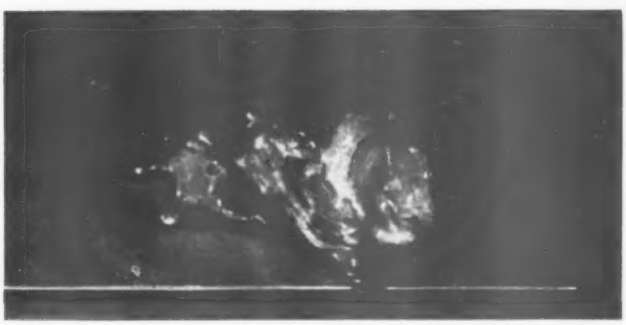
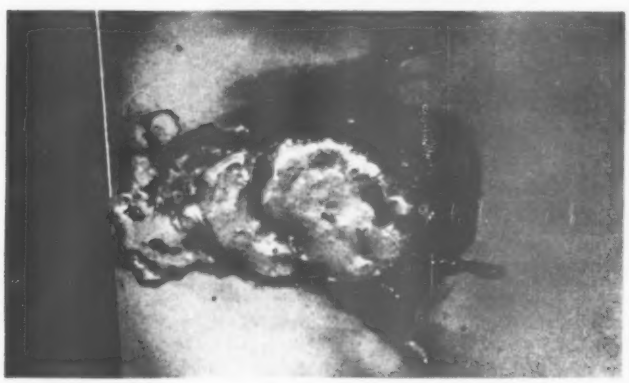
Following this operation, the web plate is flopped over to expose the other unwelded surface. Since it is now resting on the 4-in. high angle irons welded earlier, the Unionmelt head is raised to this new level by means of a telescopic tubing. Seventeen sections of 6- x 4- x $^1/_2$-in. floor angles are clamped into place, about 5 in. apart, along the top length of the web plate, backing up the already welded inside floor angles. These will be the outside floor angles of the side sill. Spacer plates are placed between the separated floor angles permitting uninterrupted welding, as Fig. 3 shows. This $^1/_4$-in. fillet weld is made at a speed of 30 ipm, using the same materials as in the preceding operations. Approximately 154 ft of welding is required for each side sill.

Construction of the two center sills requires only a slight variation in the welding steps. Each center sill has two sets of directly opposing angle irons following the contour of the fish-belly bottom, one on either side of the web plate. This, of course, necessitates two contour-welding operations whereas only one was required on the side sills. A single floor angle is welded to the top of the center sill, and this in one piece running the length of the sill. Dimensions and welding specifications are the same as that of the side sills.

Figure 4 shows the clean, smooth welds joining the angle irons to a web plate in this project. Welding of this quality makes C&EI officials confident that their "A" frame carriage will demonstrate its worth on other future welding programs.

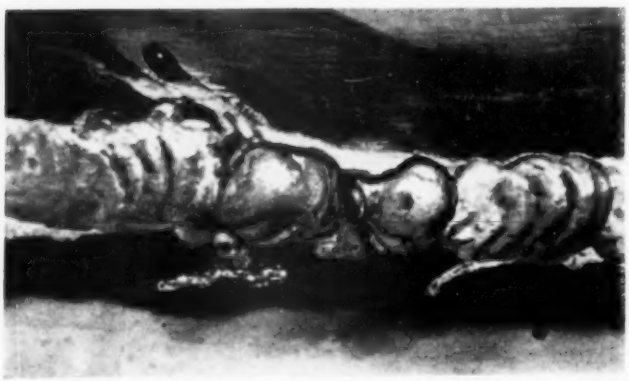
Braze-Welding Clinic

by R. L. Fuller

IF THESE THINGS HAPPEN WHEN YOU BRAZE WELD	HERE IS THE REMEDY
 In tinning—bronze rod runs to the edge of the puddle, leaving an oxidized area in the center. The molten rod bubbles and bounces like water on a hot stove.	Too much heat. Draw back the flame, or check the welding tip to make sure correct size is being used.
 In tinning—bronze rod builds up and is lumpy. Forms balls. Does not spread smoothly.	Not enough heat. Move flame closer to the metal.
 In tinning—molten bronze rod does not flow but acts as if it were deposited on a firebrick.	The metal has not been cleaned properly. Before braze welding, oil, grease, rust and any foreign material must be removed from the weld area.

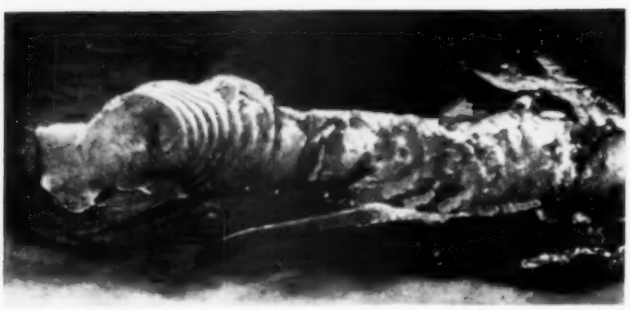
R. L. Fuller, Linde Air Products Co., New Orleans, La.

IF THESE THINGS HAPPEN WHEN YOU BRAZE WELD..... HERE IS THE REMEDY



Rod formed globules.

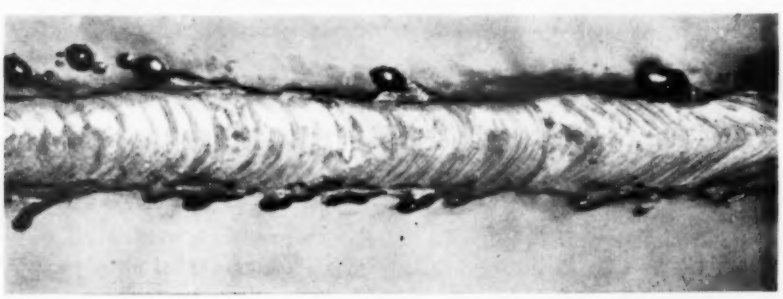
Bronze dropped from the end of the rod. Welding progressed too quickly with the result that the base metal was too cold.



Bronze has spread on too thinly and flowed out too far ahead.

Base metal was too hot. Draw back the flame.

MAKE YOUR BRAZE WELDS LOOK LIKE THIS



Here is a good braze weld. The base metal was cleaned properly to remove oil, grease, rust or oxide. The part was heated only to a dull red and then tinned. A good flux was used. The rod was held in the puddle when molten metal was added. Both rod and blowpipe were held at an angle of about 45 deg to the workpiece. (The droplets along side the weld in the picture are melted flux, and can easily be cleaned off with a wire brush).

the AMERICAN WELDING SOCIETY

activities • related events

By-Law Revisions

Official Notice to all AWS Members

It is again necessary that the national SOCIETY poll the membership by letter ballot for the approval of a number of changes in our By-Laws, such being necessary to accommodate the changing times and a pattern of improvement or expansion of membership services.

Notice is hereby given to the membership of the AMERICAN WELDING SOCIETY that in the March 1954 issue of the SOCIETY's official publication, THE WELDING JOURNAL, an official notice will be published announcing the printed publication of revisions to the SOCIETY's By-Laws. The By-Laws which are to be revised will be properly indicated by Article and Section number and the information given will include both the original and the revised text. All members will be requested to read the By-Law revisions. Not less than thirty (30) days later, a letter ballot shall be submitted to the entire membership requesting their vote thereon. The revised By-Laws shall be adopted at the expiration of sixty (60) days after mailing the ballots unless rejected by at least 20% of the eligible voting membership.

J. G. MAGRATH
National Secretary, AWS

Bound Volume 1953

Orders are now being accepted for the 1953 bound volume of THE WELDING JOURNAL at $15 each. The twelve issues of THE WELDING JOURNAL will be bound together in black imitation leather covers, together with an index covering the entire year.

The main portion of the JOURNAL contains 1250 pages of the latest and most up-to-date information on every phase of welding covering such broad subjects as aircraft welding, alloy steels, aluminum, arc studies, armor plate, brazing, bridges and buildings, ceramic coated alloys, cutting, dissimilar metals, electrodes, flame cutting, flame hardening, hard facing, human element in welding, inert-shielded-arc welding, jet engines, Magnaflux inspection, magnesium welding, maintenance, nodular cast iron; oxygen cutting, pipe welding, 60 practical welding articles, quality control, resistance welding, safety, shop repair, spot welding of aluminum, magnesium, stainless steel, titanium and other metals, storage tanks, stress corrosion cracking, structures and weldability articles. Each of the twelve issues contains sections on the SOCIETY and related activities, personnel, news of the industry, new products, new literature, new patents, Section activities and many other items.

The Research Supplement, a volume of 624 pages, is also included, representing the results of more than a million dollars worth of research.

Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Recommended Practices for Postweld Heat Treatment of Austenitic Weldments

With increased use of the austenitic steels, particularly for piping and pressure vessel fabrication, considerable confusion and misunderstanding has occurred regarding the need for stress relief and the effects of such heat treatment on the performance of weldments in service.

The *Recommended Practices for Postweld Heat Treatment of Austenitic Weldments*, just published by the AMERICAN WELDING SOCIETY, summarizes the considerations necessary to determine whether, for a given application, stress relief should be used, and if so, at what time and temperature. It was prepared by an outstanding group of Engineers serving on the Piping and Tubing Committee of the AMERICAN WELDING SOCIETY.

The recommendations represent the practices deemed most acceptable by a group of authorities on the subject, based on studies and actual industrial practice.

Copies of this four-page leaflet may be obtained at 50 cents from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Welding Exposition at Buffalo in May

The AMERICAN WELDING SOCIETY will stage its second Welding and Allied Industry Exposition at the Memorial Auditorium, Buffalo, N. Y., May 5–7, it was announced recently by Joseph G. Magrath, National Secretary. The SOCIETY's National Spring Technical Meeting will be held at the Hotel Statler in the same city, May 4–7.

The SOCIETY's first show, held in Houston, Tex., last year, attracted key executives from more than 20 industrial fields. The Buffalo exhibit will be almost twice as large and the attendance is expected to be more than three times as great. More than 100 exhibitors are expected and the products of more than 300 companies will be shown. Eighty percent of the exhibit space already has been assigned prior to public announcement of the show.

Every type of welding equipment and most accessories will be on display. Exhibits will include equipment for manufacturing and structural purposes, as well as for maintenance needs. Considerable emphasis will be placed on welding techniques for the newer metals. Many automatic welding processes also will be featured.

The announcement stressed that Buffalo was chosen as the site of the 1954 exposition because 90% of the major industrial centers of this country and Canada are within a 500-mile radius of the city and many are much closer.

In addition to the exhibits and the technical sessions, visitors also will be taken on tours of major industrial plants. In this way, visitors will have an opportunity to study the theory at the conference, compare the actual machines which do the work at the exposition and inspect practical large-scale installations in factories. The papers read at the meeting will cover every phase of welding, welding engineering, welding procedure, welding metallurgy and weldable metals.

Although the conference will be national in its approach, many of the papers read will be pointed toward the particular interests of industries within the 500-mile radius of Buffalo.

"Here, under one roof, on one floor, in but several hours, the designer or the purchasing director, the management or plant executive, the engineer or the metallurgist, the supervisor, inspector or the welder, will see exhibited and demonstrated every type of arc, gas, resistance and combined process welding machine, equipment and apparatus offered by one of America's fastest growing industries," said Mr. Magrath.

"Industry will learn how and where, right now, modern welding, brazing, cutting, heating and surface-treating processes can save their users thousands of dollars annually and result in the producing of products having reduced weight, greater strength, lower unit cost, lesser mass and superior quality; products which possess the smooth line and pleasing contours attainable only by welding; products with the eye-appeal which creates buyer-appeal," said Mr. Magrath.

Tentative Technical Program

AWS National Spring Meeting

Statler Hotel, Buffalo, N. Y.

May 4—7, 1954

TUESDAY AFTERNOON, May 4

Two Simultaneous Sessions

1—WELDABILITY

A. **Effect of Electrode Type in the Notch Slow Bend Test**
by WILLIAM J. MURPHY and R. D. STOUT, Lehigh University

B. **Effect of Thermal Activation on the Fatigue Life of Butt-Welds**
by A. M. FREUDENTHAL and ROBERT HELLER, Columbia University

C. **Temperature-Tensile Characteristics of Metal-Arc Weld Metal**
by JULIUS HEUSCHKEL, Westinghouse Electric Corp.

2—INERT ARC WELDING

A. **Sigma Welding Carbon Steel—Application Data**
by J. R. CRAIG, Linde Air Products Co.

B. **Inert-Gas-Shielded Tungsten-Arc Spot Welding**
by C. A. McCLEAN, Air Reduction Sales Co.

C. **Interrelated Factors in Process Adjustment for Inert-Gas-Shielded Arc Welding**
by EUGENE B. LaVELLE, General Electric Co.

WEDNESDAY MORNING, May 5

Three Simultaneous Sessions

3—RESISTANCE WELDING

A. **Spot Welding Thin Gauge Aluminum Alloys**
by I. W. JOHNSON, General Electric Co.

B. **Single Phase Spot Welding of Aluminum Alloys to MIL-W-6860 Specification**
by J. F. HARRIS, Taylor Winfield Corp.

C. **Flash Welding of Copper to Aluminum Tubing**
by W. F. HAESSLY, Taylor Winfield Corp.

4—STAINLESS STEEL

A. **Properties of Type 347 Welds**
by R. D. THOMAS, Jr., and L. K. POOLE, Arcos Corp.

B. **Comparison of Various Methods for the Determination of the Percent of Ferrite Content in Type 347 Stainless Steel Weld Deposits**
by W. J. FLEISCHMANN, General Electric Co.

C. **The Production of Welded Stainless Steel Pipe**
by A. GRODNER, Alloy Fabricators Division

5—SURFACING AND METALLIZING

A. **Improved Semi-Automatic Welding and Hard Facing**
by HOWARD S. AVERY, T. G. BRASHEAR, H. J. CHAPIN and G. H. EDMUNDS, American Brake Shoe Co.

B. **Fatigue Tests of Steel Specimens Prepared for Metallizing**
by R. C. MILLER, JR., and A. W. BRUNOT, Thomson Laboratory, General Electric Co.

WEDNESDAY AFTERNOON, May 5

Two Simultaneous Sessions

6—RESISTANCE WELDING

A. **Series Spot Welding of Auto-Body Steel**
by E. F. NIPPES, and F. H. DOMINA, Rensselaer Polytechnic Institute

B. **Resistance Welding of Galvanized Steel Tanks—Quality and Production Method**
by J. A. BRADLEY, Rheem Manufacturing Co.

C. **Interpretation of Standards for RWMA Type A-1 Transformers as a Basis for Correct Application**
by J. F. DEFFENBAUGH, F. E. MURRAY and V. A. RATHFELDER, Federal Machine and Welder Co.

7—PRESSURE VESSELS AND PENSTOCKS

A. **30-Ft. Diameter All-Welded Test Tank—Some Unique Design Features**
by JOHN VASTA and F. W. DUNHAM, Bureau of Ships, Navy Department

B. **Automatic Horizontal and Vertical Welding of Field Erected Structures**
by AMEL R. MEYER, Graver Tank & Manufacturing Co.

C. **Fabrication and Welding of Steel Penstocks**
by R. F. SCOTT, Horton Steel Works

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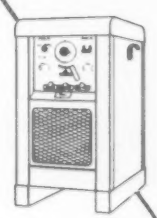
. . . you know there's none better!



ARC · SPOT miller GENERATORS WELDERS

miller ELECTRIC MANUFACTURING CO.
APPLETON, WISCONSIN

THURSDAY MORNING, May 6

Three Simultaneous Sessions

8—TITANIUM

A. **Surface Embrittlement of Titanium by Exposure of Weld Heat-Affected Zone to Atmospheric Contamination**
by C. E. HARTBOWER, D. M. DALEY, JR., and W. P. HATCH, Jr., Watertown Arsenal

B. **The Effect of Alloying Elements on Welds in Titanium. Part II**
by G. E. FAULKNER, Battelle Memorial Institute

C. **High-Temperature Alloy Fusion Brazing for Titanium and Titanium Alloys**
by ROGER A. LONG and ROBERT RUPPENDER, Aircraft Components Division, Ferrotherm Co.

9—STRUCTURAL

A. **Special Problems in Structural Welding for Bridges**
by STEWART MITCHELL and ARTHUR L. ELLIOTT, California Division of Highways

B. **The Reconstruction of the MacArthur Bridge Across the Mississippi River at Burlington, Iowa**
by NED L. ASHTON, State University of Iowa

C. **New Principles for the Calculation of Welded Joints**
by PROF. C. G. J. VREEDENBURGH, University of Delft

10—PROCESS AND EQUIPMENT

A. **Manual Guided Submerged Melt Welding**
by R. A. KUBLI, Linde Air Products Co.

B. **Selection of D-C Arc Welding Power Sources**
by A. U. WELCH, General Electric Co.

C. **D-C Arc Welders—Rectifiers or Motor Generator Sets?**
by S. OESTREICHER, Harnischfeger Corp.

FRIDAY MORNING, May 7

Three Simultaneous Sessions

11—NONFERROUS

A. **Brazing Molybdenum for High-Temperature Service**
by M. I. JACOBSON, D. C. MARTIN and C. B. VOLDRICH, Battelle Memorial Institute

B. **Welding of 90/10 Copper-Nickel Alloy**
by G. R. PEASE and T. E. KIHLGREN, International Nickel Co.

C. **Adhesive Bonding Complements Soldering and Brazing**
by H. SIMONS, Eutectic Welding Alloys Corp.

12—PIPING AND TUBING

A. **Validity of Radiography in Predicting Pipeline Joint Strengths**
by RICHARD C. WILEY, California State Polytechnic College

B. **Elimination of Backing Ring by Use of Consumable Insert**
by J. V. HARRINGTON and T. A. RISCH, Electric Boat Division, General Dynamics Corp.

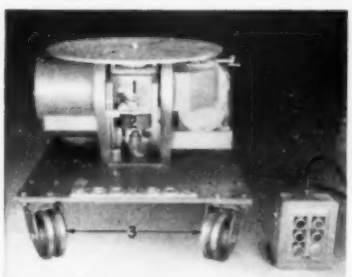
C. **Welding Procedure for Welding Tubes in Heat Exchangers**
by W. E. BATTLES and W. E. SPIRES, Leader Iron Works, Inc.

13—APPLICATIONS

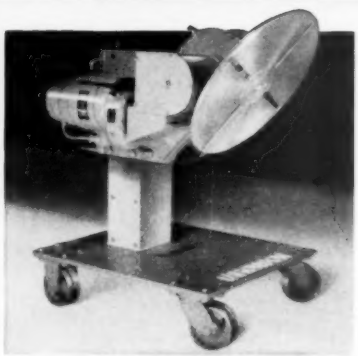
A. **Some Practical Considerations in the Application of Tungsten Arc Welding**
by H. A. HUFF, JR., Air Reduction Sales Co.

B. **Industrial Research and Procedure Control as Applied to Automatic Welding Processes**
by WARNER H. SIMON, Dresser Manufacturing Division, Dresser Industries, Inc.

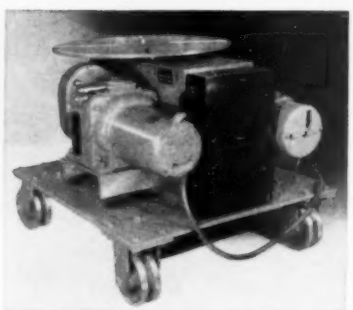
Aronson Model "D" = MOST machine for LEAST money!



Front view shows 1-Free-Wheeling adjustment. 2-CYL Air Cylinder clamping device. 3-Front Casters swivel (rear casters rigid).



Quarter view shows chassis elevated. 135° table tilt — Tilt motor with brake.



Rear view shows Infinitely Variable Transmission with micrometer control — Magnetic reversing starters for Tilt and Rotation.

COMPARE...

1 SMALLEST 1000 lb. POSITIONER: 18" high, 30" wide, 34" long! COMPACT — MIGHTY!

2 HIGHEST PRECISION: 1% Speed Control; Minimum Backlash; 1° Tilt Accuracy!

3 MOST VERSATILE: ZERO to 3.75 RPM Table Rotation; Built-In Free-Wheeling; 20 seconds for Full Tilt with Magnetic Braking; Adjustable Table Height from a LOW 18" to a HIGH 32"; HOLLOW SPINDLE, tapped both ends; Precision Machined Table; Built-In MERCURY GROUND Main Spindle!

4 HIGHEST QUALITY: Anti-Friction Bearings Throughout, no bushings; Oil-Tight Dust-Tight Push Button Station at LOW VOLTAGE; Magnetic Reversing Starters; Aluminum Bronze Worm Gears; NO PERIODIC MAINTENANCE!

SEND FOR OUR LATEST, CATALOG SHOWING THE COMPLETE LINE OF ARONSON WELDING POSITIONERS

Aronson MACHINE CO. WORK WORK **ARCADE, N. Y.**

Remember — the trade marks "tt" and "TUBE-TURN" are applicable only to products of TUBE TURNS, INC.

Engineered FOR ENDURANCE

THIS TUBE-TURN WELDING TEE is drawn from seamless tubing to a barrel shape—the form every tee wants to assume under pressure. This design, plus the generous crotch radius and thickness, assure exceptional strength and endurance. In tests of representative fittings, bursting pressures have averaged over 25% higher than required by applicable standards.

This extra quality at no extra cost is typical of all TUBE-TURN Welding Fittings and Flanges. For satisfying service, and to fill all your requirements from one reliable source, get in touch with your nearby TUBE TURNS' Distributor. You'll find one in every principal city.

The Leading Manufacturer of Welding Fittings and Flanges

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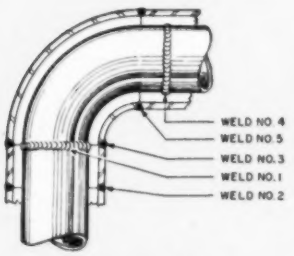
ENGINEERING SERVICE

TUBE TURNS' ENGINEERING SERVICE

develops new method of fabricating jacketed fittings

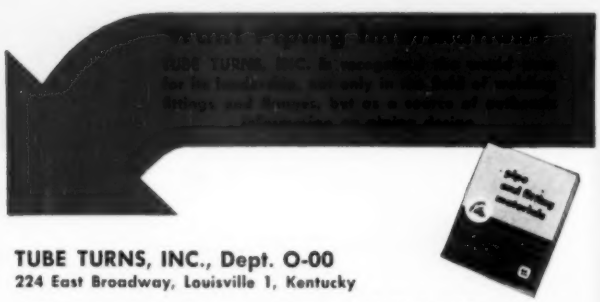
FABRICATION TIME AND COST can be reduced with this method of using welding fittings for directional changes in jacketed piping systems. The jacketed fitting combination consists of long and short radius TUBE-TURN Welding Elbows, with center-line radii closely matching. A tangent on one end of the inside elbow (see cut) extends beyond the corresponding end of the outside elbow. On the other end a short length of pipe is attached to simplify installation.

The method eliminates the need for steam and coolant jumpers, and also eliminates flanged joints, except where disassembly must be provided for. Insulation can be readily applied. Maintenance costs are sharply reduced, as all joints are permanently leakproof. The assembly provides optimum flow conditions, and minimized thermal problems.



Welding sequence for elbow of jacketed system.

This improved technique is another contribution to piping technology by TUBE TURNS' Engineering Service Division—always ready to help you with special piping problems.



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Please send me free copy of Pipe and Fitting Materials.

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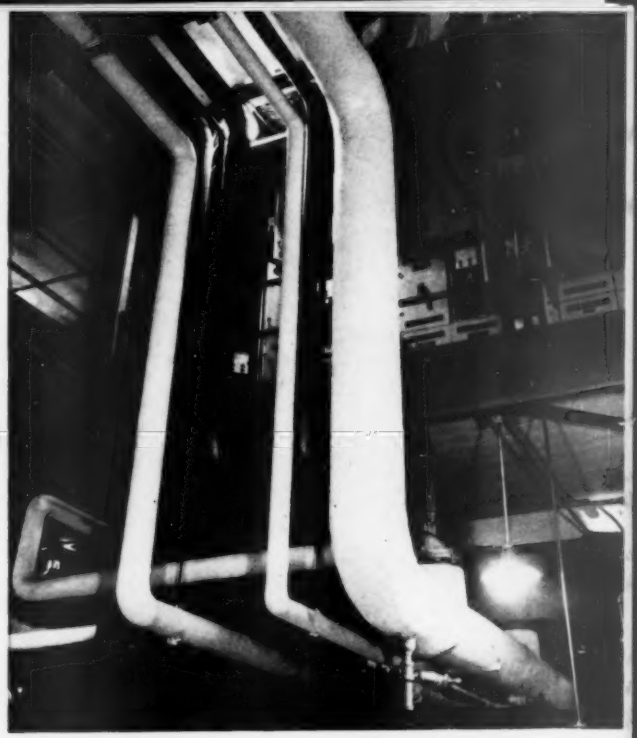
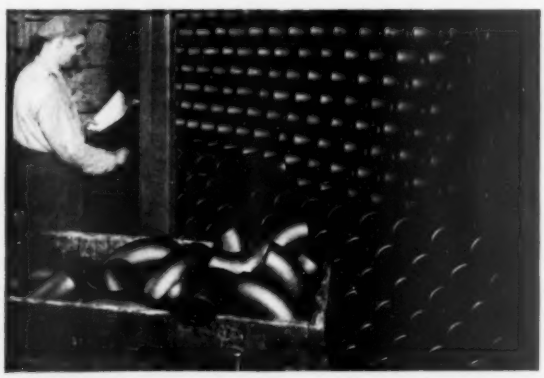


These water, steam, and air lines, using TUBE-TURN Welding Fittings to make directional changes, provide permanently leakproof service. Note compactness of layout, and how neatly insulation is applied.



SERVICE is the middle name of your nearby TUBE TURNS' Distributor. He can help you fill all your requirements from one reliable source. TUBE TURNS, INC. offers the world's broadest line of welding fittings and flanges, in a wide range of types, sizes, and more than 40 different alloys.

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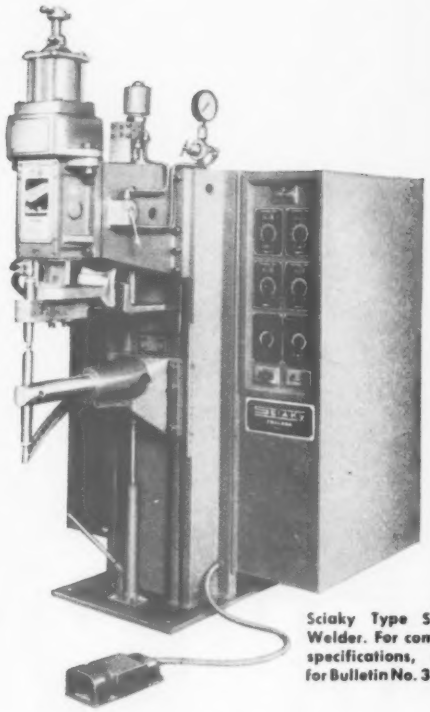
TUBE TURNS, INC.

LOUISVILLE 1, KENTUCKY

STANDARD WELDER ADAPTED FOR SPECIAL APPLICATIONS



Sciaky Type SPT 2 Welder. For complete specifications, write for Bulletin No. 306-1.

Two Standard Sciaky Three-Phase Welders Join 42 Parts in 4 Operations

A short time ago Casco Products Corporation, Bridgeport, Conn., consulted Sciaky about special equipment for resistance welding simulated wire wheels for automobiles.

Power limitations at Casco were further complicated by design requirements . . . 40 spokes of .430 stainless steel joined to retainer rings . . . accurate fit on the automobile wheel demanded precise alignment of welded assembly...production rate of 1200 per day...strength to withstand vibration and shock of wheel rotation.

Avoiding the expense of special machines, Sciaky adapted two standard type SPT 2 welders with special tooling for multiple gun operation. Only four operations were required to join the 42 parts of the assembly.

Sciaky patented Three-Phase operation readily satisfied existing power facilities where conventional single phase could not. Sciaky Three-Phase, also, provided precise control to maintain tolerances of setdown and alignment.

The strength of the spot welded assembly exceeded requirements, and Sciaky Three-Phase produced a smooth fillet at weld eliminating need for special metal finishing. Production requirements were satisfied.

Write for the complete story of Casco's use of Sciaky welders for this job. Ask for "Resistance Welding at Work", Volume 3, No. 9.

Largest Manufacturers of Electric Resistance Welding Machines in the World

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NEMA-rated at 200 amps.

—but pulls 300 amps.!

Runs all day on one tank of gas!

New P&H WN-250 Engine-Driven

Here you get everything you've ever wanted in an engine-driven welder — including features you don't get from any other.

Take a quick look at some of the WN-250 advantages that help you keep step with demanding production schedules; help you cut costs:

(1) The P&H WN-250 has more capacity than other welders with the same rating.

(2) It has a full 20-gallon gas tank.

(3) It gives you the latest-type P&H welding generator, powered by a direct-connected gasoline engine. It's a four-cylinder, 180GLU Waukesha, water-cooled and built for heavy duty. And we really mean *heavy* duty — it's not an automotive light-weight. Available with electric starter.

(4) The WN-250 is equipped with a P&H idling device that establishes the rated speed of 1800 rpm as soon as the arc is struck. This speed is maintained for a set period after the arc is broken.

(5) It has P&H's famous Dial-lectric Control. An easy turn of a radio-type knob provides stepless heat adjustment over the entire high or low range.

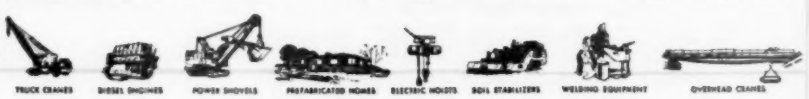
(6) It has pre-lubricated bearings, to reduce the need for servicing and insure longer life.

(7) It has an auxiliary AC power supply (1KVA) that permits floodlighting and running power tools, while welding.

There are other reasons why you're money ahead with a P&H WN-250. Ask your P&H representative or distributor for all the facts. Or, write for bulletin.

P&H WELDING DIVISION
HARNISCHFEGER CORPORATION
0000 West National Avenue • MILWAUKEE 46, WIS.

the P&H *line*



Both engine and generator are mounted on a sturdy frame. Two-wheel mounting also available.

Arc Welder

Continuous 8-hour welding test demonstrates the extra stamina of the P & H WN-250

You can't beat welding performance like this: In a recent test, the P&H WN-250 operated continuously for 8 hours on a 70% duty cycle.

A $\frac{5}{32}$" electrode was used with 300 feet of cable. There were 250 amps. at the electrode. So that the test would be continuous, three welding operators were used. When one got tired, another took over. All used the drag technique with a 6010 rod — which is as close to a short circuit as you can get.

At the end of 8 hours, the P&H generator was still cool. And the WN-250 was still rarin' to go — the weldors were worn out, but not the machine.

America's most complete line of Arc-welding equipment and electrodes

P&H AC WELDER

A full range of sizes up to 625 amps. (NEMA-rated). All are connectable to 220 or 440 volts. Dial-lectric Instantaneous Remote Control is fingertip control — gives you any heat you want—right at the work.

P&H DC RECTIFIER WELDER

Three sizes — 200, 300, and 500 amps. (NEMA-rated). No moving coils — no bearings, brushes, commutator, brush riggings, etc. Dial-lectric Control gives you finger-tip heat-control at the work.

P&H POSITIONERS

One finger is enough to position heavy weldments for economical downhand welding. Capacities from 2500 to 36,000 lbs. — remote control and hand operated models.

P&H ELECTRODES

A type and size for every job — to give you cleaner, sounder welds at lower cost on mild steel, cast iron, "hard-to-weld" steels, stainless steels, or hard surfacing.

P&H Welding equipment is manufactured and sold in Canada by

REGENT EQUIPMENT MANUFACTURING COMPANY LTD.

455 King Street West • Toronto, Ontario, Canada

NEWS OF THE INDUSTRY

Coming Events

International Acetylene Association: Annual Meeting, Palmer House, Chicago, April 7–9, 1954.

Society for Experimental Stress Analysis: Spring Meeting, Educational Lecture and Exhibit, April 14–16, 1954, Netherlands Plaza Hotel, Cincinnati, Ohio.

American Welding Society: National Spring Technical Meeting, Statler Hotel, Buffalo, May 4–7, 1954—and in conjunction, the AWS sponsored Welding and Allied Industry Exposition at the Buffalo Memorial Auditorium, May 5–7.

American Welding Society: 1954 National Fall Meeting, Hotel Sherman, Chicago, Nov. 1–5.

National Welding Supply Association Meeting

Rallying to the Zone Creed, the Southeastern Zone held its most successful meeting to date at the Dinkler-Tutwiler Hotel in Birmingham, Ala., on Monday and Tuesday, December 7th and 8th.

Attendance was at a new high with 108 distributors and manufacturers present. Comments received after the meeting indicated that the talks presented by the speakers proved most interesting and constructive.

The meeting was ably conducted by W. P. McLendon, Keenan Welding Supplies Co., Vice-President of the Southeastern Zone.

Following his introductory remarks, Vice-President McLendon introduced President W. A. Rice, Virginia Welding Supply Co., whose address entitled "Let's Talk About George" was warmly received. A. E. Pearson, Chief Welding Engineer, Ingalls Iron Works Co., Birmingham, Ala., next spoke on "A Customer's View, of Welding Supply Companies." The final speaker on Monday morning was E. C. Caluwaert, O.K.I. Welding Supply Co., Cincinnati, Ohio, who selected as the title of his talk, "Be Yourself."

The afternoon session opened with a very interesting address by James H. Gray, Editor, *Albany Herald*, Albany, Ga., on "Why I Came South." Following Mr. Gray's address, a panel of the following three members discussed in a most interesting manner the subject "We Are Reducing Operating Costs By . . . ." B. F. Conner, Delta Oxygen Co., Inc., Memphis, Tenn. (warehouse economies), J. L. Kirk, Jr., Pocahontas Welding Supply Co., Bluefield, W. Va. (delivery economies); R. H. McLean, Jr., Hampton Roads Welders Supply Co., Norfolk, Va. (office economies).

Charles L. Malott, Price-Bass Co., Nashville, Tenn., next discussed in a highly spirited manner "How to Stimulate Your Sales Organization."

Included on the afternoon program through the cooperation of *Industrial Distribution*, a McGraw-Hill publication, was a presentation of the film, "Operation Teamwork."

The Tuesday morning session opened with a discussion of "The Importance of a Balanced Inventory—Its Value as a Sales Aid," capably led by T. L. Andries, Andries Welding Supply, Jackson, Miss., after which delegates were privileged to hear an excellent address by E. A. Clevenger, Vice-President, Corley Mfg. Co., Chattanooga, Tenn., on "The Importance of Aggressive Merchandising."

The remainder of the session was devoted to viewing the 120 slides of distributors operations. The presentation of the program evoked considerable interest.

Three Concerns Team Up to Get Navy Off Spot

Three companies have helped out the Navy through a combination of design and manufacturing methods. They are about to deliver to the Philadelphia Navy Yard a portal gantry crane of extraordinary reach and lifting capacity.

The Navy found no equipment at Philadelphia to reach the new and higher top hamper of the Essex class aircraft carriers which it is modernizing. So it called on the Derrick and Hoist Co., Inc., of Long Island City.

The conventional riveting or bolting of forged or cast parts involved impossible patterns and costly procedures, and Derrick and Hoist, in turn, called on the Acme welding division of the United Tool and Die Co. at West Hartford, Conn.

It made the needed drums and bolsters out of steel weldments that assured smoothness and uniformity of strength. The American Bridge Co. is supplying and erecting structural steel parts.

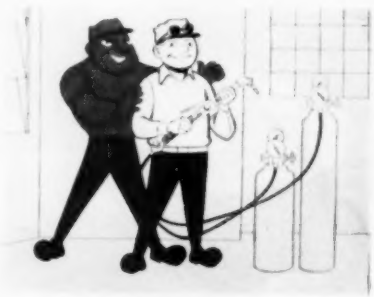
Powered by its own Diesel-electric generator with specially developed controls of great delicacy, the giant travels the dockside and swings its 230-ft. boom a full 360°.

(Taken from the New York *Times*, Sunday, Dec. 27, 1953.)

New Welding Safety Film

Air Reduction has just produced a new sound slide film on safety in the use of oxy-acetylene cutting and welding equipment.

The film, "The Guy Behind Your Back," is a fundamental approach to the factors affecting safety when operating oxy-acetylene welding and cutting torches and cutting machines. It is specifically designed for companies to train their own employees.



The story is presented in an amusing way by the use of many cartoons and an easy-going narrative. It is a light, but not comic, approach planned to make the serious business of safety in welding easy to absorb.

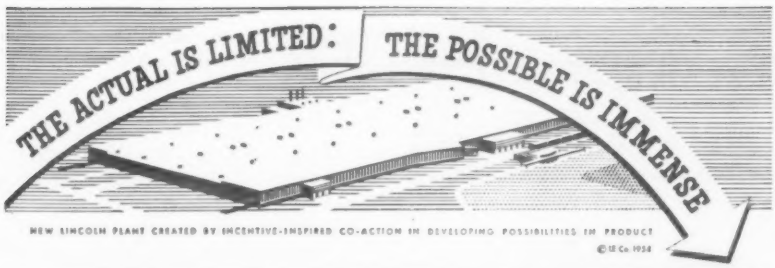
Free showings of this 20-minute film may be arranged for by getting in touch with the Air Reduction office in your vicinity. Also, copies of the film may be purchased from any Airco office at the nominal cost of $15 each.

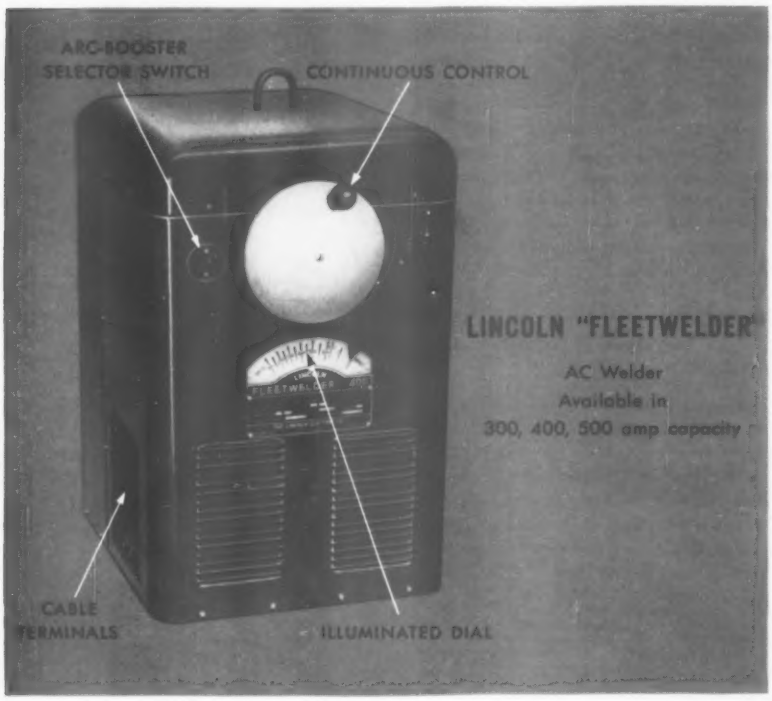
Additional information may be obtained by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Fansteel Changes Subsidiary Name

WW Alloys, Inc., Division of Fansteel Metallurgical Corp., is the new name of the wholly owned subsidiary formerly known as Weiger Weed & Co.

The name change was announced recently by Robert J. Aitchison, Fansteel Chairman of the Board. "The change was made to provide a name more truly descriptive of the division's products and activities," stated Mr. Aitchison. "For several years, the division has produced spot-welding electrodes, seam welding wheels, water-cooled holders and other products for resistance welding. Now that the division is expanding into the pro-


THE ACTUAL IS LIMITED:
THE POSSIBLE IS IMMENSE
NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT



AC WELDING MADE SIMPLER

• **Easy Current Selection.** A few turns of "Fleetwelder's" dial-operated Continuous Control select any current from a wide welding range. The exact welding current is indicated on an illuminated dial that also shows whether the machine is turned on or off.

• **Current Stays Set.** Rugged holding devices maintain accurate current settings. There are no sliding mechanisms or moving coils to become loose as the arc is struck.

• **Safe to Operate.** "Fleetwelder's" open circuit voltage is held to 71 volts for safety. Where specified, open circuit voltage can be limited to 24 volts by an optional safety contactor.

• **Arc is Self-Starting.** There is no more electrode sticking to slow up welding operations as on conventional AC machines when lighter currents and smaller electrodes are used. "Fleetwelder's" Arc-Booster starts the arc instantly each time the electrode touches the work.

• **Quality Comes Easier.** Lincoln's hot-start arc prevents cold overlaps . . . insures instant penetration at the start of every weld, an advantage for tack or plug welding.

ONLY FLEETWELDER'S HIGHER USEABLE CURRENT REALLY CUTS AC WELDING COSTS

It's so . . . By taking advantage of Lincoln's higher useable currents, you can now weld faster . . . use larger diameter electrodes to cut AC welding costs 10% and more. That is why the "Fleetwelder" starts saving money on your very first job . . . and for these reasons:

1. Higher Useable Current There are more *reserve* amps . . . up to 50% added current . . . in the "Fleetwelder" to put to work on your welding jobs. As a result, you get more amps per dollar with Lincoln than with any other welder.

2. Complete Overload Protection It is safe to operate at "Fleetwelder's" additional current because of built-in thermostats that cut out the magnetic starter . . . eliminating all danger of burn-out . . . *a feature found only in Lincoln.*

"Fleetwelder" Pays for Itself. Labor and overhead savings through "Fleetwelder's" faster operation return your investment in surprisingly short period. Have your Lincoln representative show you how. Write

SEND FOR BULLETIN

Complete description and specifications on "Fleetwelder" are in Bulletin 1314, available by writing on your letterhead.

THE LINCOLN ELECTRIC COMPANY

Dept. 1901
CLEVELAND 17, OHIO

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

duction of copper base alloys for other applications, a name of a more metallurgical nature is desirable."

The headquarters of WW Alloys, Inc., is 11644 Cloverdale Ave., Detroit 4, Mich.

Arc Welding Sets

Units Ordered, Excluding Exports

	Single Operator, Variable Voltage, DC Sets			Transformer Welders	
	Motor Drive	Engine Drive	Generators Only	Industrial Type	Limited Input Type
1953					
Jan. ..	1,757†	862	27	1,195	1,227
Feb. ..	1,593†	715	39	1,342	997
Mar. ..	1,669†	1,008	73	1,706	1,410
Apr. ..	1,558†	819	19	1,463	1,217
May ..	1,402†	887	24	1,180	831
June ..	1,314†	1,096	47	1,040	725
July ..	1,337†	826	32	1,076	635
Aug. ..	1,260†	736	27	925	601
Sept. ..	1,398†	836	38	785	677
Oct. ..	....	....	....	....	....
Nov. ..	....	....	....	....	....
Dec. ..	....	....	....	....	....
1952	18,932	11,104	277	16,794	15,489
Jan. ..	1,546	1,119	7	1,362	1,496
Feb. ..	1,517	933	26	1,471	1,323
Mar. ..	1,569	794	40	1,642	1,399
Apr. ..	1,329	1,277	21	1,476	1,941
May ..	1,872	1,025	5	1,596	2,087
June ..	1,401	975	13	1,438	1,518
July ..	1,182†	847	35	1,233	1,235
Aug. ..	2,157†	811	24	1,434	1,353
Sept. ..	1,565†	761	26	1,535	1,374
Oct. ..	1,588†	1,059	7	1,156	1,442
Nov. ..	1,471†	765	27	981	892
Dec. ..	1,735†	745	46	1,303	1,124
1951	13,048	10,333	485	15,645	16,954
1950	10,115	8,207	272	9,852	16,474
1949	7,393	6,193	256	7,295	12,847
1948	10,927	10,435	395	8,792	13,890
1947	13,677	10,822	1,169	9,719	13,034
1946	16,467	10,622	2,818	21,093	16,949
1945	20,716	8,776	2,795		21,448
1944	30,230	6,023	3,140		15,426
1943	30,437	4,747	2,068		4,439
1942	60,264	5,051	2,674		8,236
1941	35,856	4,412	1,415		4,217
1940	13,646	2,649	1,168		2,478

† Includes rectifier type
National Electrical Manufacturers Association

Taken from 1954 Steel Metalworking Yearbook

Employment Service Bulletin

Position Vacant

V-307. Young Engineer wanted. A nationally recognized cooperative welding research organization desires to secure the services of a graduate mechanical or metallurgical engineer to act as executive secretary of a large, important committee in the pressure vessel field, with a number of subcommittees. Man with good personality, some research experience, report writing desired. Opportunities for advancement. Salary to start $6000 to $6500, depending on age and experience.

Services Available

A-644. Welding Supervisor, 23 years in welding field, last 14 in supervision of welding and cutting and related crafts. Nine years with two major oil companies in South America. Thorough knowledge fabrication of mild steel plate and pipe, low- and high-alloy materials; visual, Magna-Flux and X-ray inspection. Ample job-shop and ship repair. Interested in foreign or domestic employment. Family man and good habits. Résumé upon request.

A-645. Welding Foreman. Sixteen years' experience, including supervisor of manufacturing department; liaison between design engineering and manufacturing departments in new designs, methods and procedures; responsibility for conducting tests of welding methods, techniques and new equipment; instruction and testing of welders; time studies and planning of assembly sequence. Full knowledge of arc and acetylene welding and burning, high-pressure vessel work, submerged arc welding. Familiar with low chrome alloys, stainless steel, etc. Age 37, married. Further details upon request.

A-646. Welding Supervisor, 37 years of age. Experienced as welder, welding instructor, foreman, inspector and liaison work. Heavy in production welding of road-building equipment.

A-647. Metallurgical Chemist with long experience in welding research and in designing and manufacturing coatings for arc welding electrodes and brazing rods. Knowledge of foreign languages. Résumé upon request.

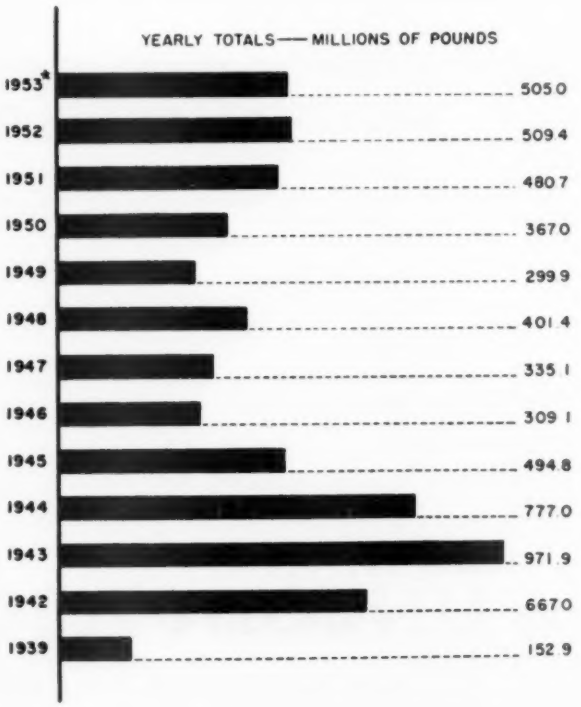
WELDING ELECTRODES

Shipments in Pounds

	Mild Steel	Alloy	Nonferrous	Total
1953				
9 Mos..	341,005,772	64,522,338	1,574,249	407,092,359
Jan. ...	48,053,802	7,856,755	135,197	56,045,754
Feb. ...	42,907,987	8,501,619	248,148	51,657,754
Mar. ...	47,248,343	9,208,469	288,454	56,735,266
Apr. ...	41,415,452	8,821,643	136,235	50,373,330
May ...	40,753,719	6,744,714	221,600	47,720,033
June ...	36,622,679	7,366,452	136,685	44,125,816
July ...	28,902,745	5,980,897	121,047	35,004,689
Aug. ...	25,656,698	4,945,935	168,704	30,771,337
Sept. ..	29,444,347	5,095,854	118,179	34,658,380
Oct. ...	.....	.....	.....	.....
Nov. ...	.....	.....	.....	.....
Dec. ...	.....	.....	.....	.....
1953*	.....	.....	.....	505,000,000
1952	425,290,499	82,633,922	1,519,208	509,443,629
1951	413,444,913	65,903,970	1,361,836	480,710,719
1950	322,954,832	42,574,710	1,861,686	367,391,228
1949	273,463,740	24,753,807	1,715,362	299,932,909
1948	369,019,831	30,214,928	2,124,496	401,359,255
1947	307,756,495	25,172,382	2,149,768	335,078,645
1946	284,126,356	24,991,208†	.....	309,117,564
1945	435,789,217	59,029,938†	.....	494,819,155
1944	707,756,964	69,236,137†	.....	776,993,101
1943	.....	.....	.....	971,929,782
1942	.....	.....	.....	666,965,595
1939	.....	.....	.....	152,863,373

† Includes both alloy and nonferrous electrodes. * Estimated.

National Electrical Manufacturers Association



Taken from 1954 Steel Metalworking Yearbook

A NEW INVENTION

THE greatest development in cylinder manifold design and construction in over four decades.

Now you can assemble a cylinder manifold right on the job, without special tools; it can be shipped in ordinary boxes and put together with the ease expected of a modern "erector set." All parts fit snugly, leakproof and assure accurate over-all dimensions.

And—when desirable, the manifold may be expanded to meet increased gas capacity or you can take it apart for removal or storage; the newly invented "differential thread" joint makes all of these long hoped for qualities a reality.

NOW—you are the doctor; you may design and assemble cylinder manifolds to meet YOUR NEEDS and SPACE REQUIREMENTS RIGHT ON THE JOB—and your cylinder manifold will never become obsolescent or inadequate. YOU CAN EXTEND IT AT YOUR WILL. GET THE FACTS . . . WRITE TODAY . . . GET THIS EXCITING NEWS ABOUT A REALLY GREAT IMPROVEMENT IN CYLINDER MANIFOLD DESIGN AND ASSEMBLY METHOD.

DEALERS AND DISTRIBUTORS NOTE: now you can carry IN STOCK all of the parts needed for any size or type of cylinder manifold . . . no loss of orders because you must await a factory shipment. Why not write today for full information—it's worth your time.

Made by National SINCE 1910 WELDING EQUIPMENT CO., San Francisco 5, California

831

NEW LITERATURE

Ampco 8 Welding Procedures

Ampco 8 sheet and plate which is available in all thicknesses for fabrication can be welded by all of the arc-welding processes, i.e., carbon-arc, metal-arc, inert-gas tungsten-arc, inert-gas consumable electrode and submerged-arc.

Detailed welding procedures are available upon request covering all of the above welding processes from Ampco distributors or direct from Ampco Metal, Inc., Milwaukee 46, Wis.

Alloys and Fluxes

Just published is a handy, pocket-size, buyers guide to the complete line of All-State alloys and fluxes for welding, brazing, soldering, cutting and tinning practically all of the commercially used metals.

Though the new guide covers many more products than had been offered previously, it has been edited to condense complete buying information into 24 pages, 3¼ x 6 in., as compared with 32 same size pages required earlier. The data have been better arranged and set in larger type.

Copies may be obtained from any All-State distributor and from All-State Welding Alloys Co., Inc., White Plains, N. Y.

Tweco Products

Tweco Products Co., Wichita, Kan., has just released a new 12-page catalog covering their complete line of electrode holders, ground clamps, cable connectors and cable accessories for arc welding.

Identified as the Twecolog No. 9, this colorful new catalog contains full information on the Tweco line, including consumer quantity prices. It will be of interest to those engaged in arc welding. A copy will be sent on request.

Exhausters

Ten Torit exhausters are described in a new folder just issued by the Torit Manufacturing Co. Ranging in capacity from 350 to 4000 cfm, these exhausters will remove fumes, odors, gases, etc., from industrial operations such as welding, soldering, metallizing, in fact wherever these fumes may be safely discharged out-of-doors.

Compact, portable units, these Torit exhausters may be installed simply and economically with flexible metal or rubber tubing to suction fumes directly from the immediate working area. Ventilation is provided only at the time the operation is being performed, to minimize power consumption.

For complete information write the Torit Manufacturing Co., 271 Walnut St., St. Paul 2, Minn.

Stranded Electrodes

"Stranded Electrode Materials for Aircomatic Welding" is the title of a new 12-page reprint being offered by Air Reduction.

Reprinted from THE WELDING JOURNAL, this article discusses the use of stranded wires in the inert-gas-shielded metal-arc consumable electrode Aircomatic welding process.

Some of the points covered include: construction of stranded electrodes with close-up photographs showing how the wires are interwoven; welding characteristics of a stranded electrode with photomicrographs of deposits; and case history applications complete with illustrations showing where stranded electrodes have been used with success.

A copy of this booklet may be obtained by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Welding Bulletin

Welding with Ampco Bronze Electrodes-Filler Rod-Wire is the title of the new 24-page Bulletin W-17 recently issued by Ampco Metal, Inc., Milwaukee, Wis., describing the complete line of products for use with metal-arc, carbon-arc, inert-gas tungsten-arc, submerged-arc and inert-gas consumable electrode processes.

A copy of this bulletin can be secured from Ampco distributors, Ampco representatives or by writing direct to Ampco Metal, Inc., Milwaukee 46, Wis.

Resistance Welding of Aluminum and Aluminum Alloys

Continuing its series of bulletins on various phases and applications of resistance welding, the Resistance Welder Manufacturers' Association has just released a new bulletin—No. 18 in the series—entitled *Aluminum Welding.*

This bulletin covers in detail the preparation of aluminum and aluminum alloys for welding, as well as giving the technical aspects of the welding process.

The 21-page booklet contains a number of helpful diagrams and tables, as well as many photographs.

Copies are obtainable at the headquarters of the Resistance Welder Manufacturers' Association, 1900 Arch St., Philadelphia 3, Pa., at 20¢ each.

Farm Arc Welding

This new handbook for building, repairing and servicing farm equipment by V. J. Morford, Professor, Department of Agricultural Engineering, Iowa State College of Agriculture and Mechanic Arts, was first printed in January 1954. It contains 456 pages with 742 drawings and photographs; gives plans, bills of materials and suggestions for hundreds of farm projects and is bound in semiflexible board, covered with gold embossed simulated leather.

This book may be ordered direct from The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio. Price $2.00 in USA; $2.50 elsewhere. Postage prepaid.

Welding Flux

A pamphlet describing the use of a new Solar welding flux—Type 202, for welding aluminum and its alloys—is obtainable from Solar Aircraft Co.

A major advantage of the new aluminum flux is that the welder has a clear view of the naked puddle, and no wiping is necessary. Another cost-saving feature is the effective cleaning action of Type 202, which eliminates the need for pickling prior to welding.

Copies of the booklet on Solar 202 flux can be obtained from the Flux Department, Solar Aircraft Co., 2200 Pacific Highway, San Diego 12, Calif.

Leather and Asbestos Garments

A new, illustrated, four-page, two-color folder on the uses for and many outstanding features of Amcoweld leather and asbestos garments for the protection of welders has recently been published by Eastern Equipment Co., Inc., Willow Grove, Pa. Included in the folder is a description of such garments as capes, coat, jacket, pants, chaps, sleeves, bibs, gloves, mitts, spats and aprons all made to highest standards from pearl gray, soft, pliable, heat-resistant, chrome-tanned leather. A helmet with headgear and a chrome leather electrode carrier are also illustrated and described. Asbestos garments including five finger gloves, leather faced gloves, finger mitts and reinforced mitts all made from Underwriters' grade asbestos cloth and double stitched to provide long service life are illustrated and described in another section of the folder.

For your free copy of "Amcoweld Leather & Asbestos Garments for Welders," write Eastern Equipment Co., Inc., Willow Grove, Pa.

Welding End Specifications

The practice of welding valves into lines for high-pressure, high-temperature service is becoming more and more prevalent, and with it has come a need for dimensional standardization. In an effort to meet this need, Edward Valves, Inc., a subsidiary of Rockwell Manufacturing Co., has published a bulletin listing socket welding end and butt welding end dimensions as approved by the AMERICAN WELDING SOCIETY.

Socket welding end dimensions are given for valves 2 in. and smaller. Butt welding end dimensions are given for pipe sizes from $2^1/_2$ to 16 in. Included in the bulletin are four diagrams indicating the standard preparation of valve butt welding ends. The 4-page bulletin, No. 507, may be obtained by writing to Edward Valves, Inc., East Chicago, Ind.

Good Painting Practice

The Steel Structures Painting Council, 4400 Fifth Ave., Pittsburgh 13, Pa., has issued a volume of 423 pages, $8^1/_2$ x $11^1/_4$, on every phase of painting steel structures. The book sells for $5.00 per copy. There is a section relating to the effect of painting on welding.

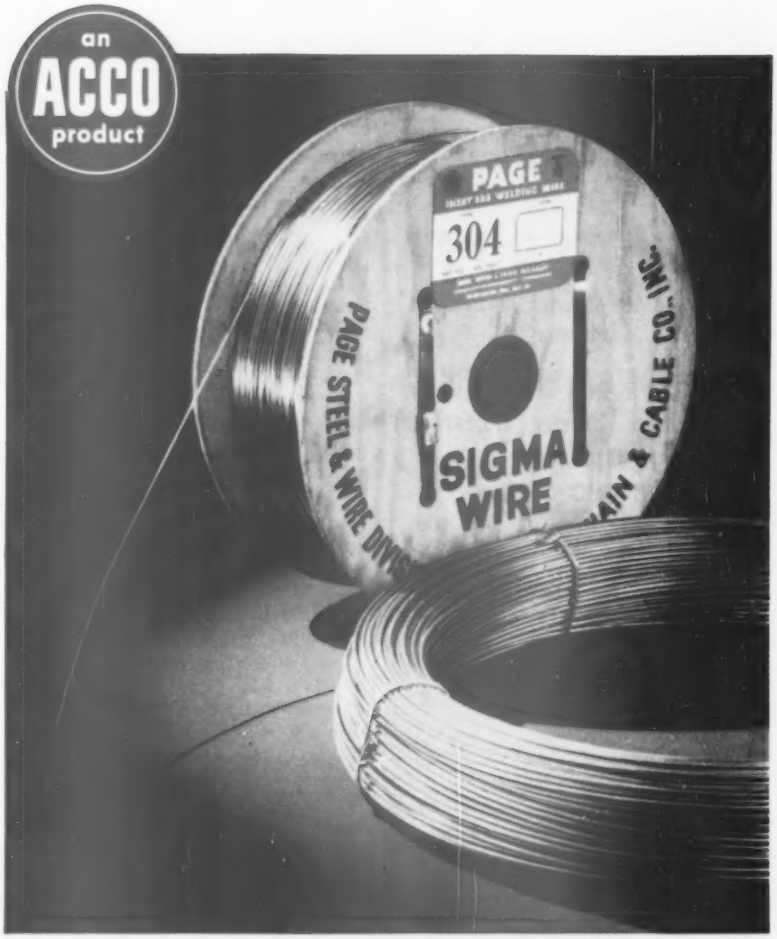
Now you can accurately, easily flame cut all kinds of shapes — circles, angles, bevels, straight lines. NEECO cutting guides convert ordinary hand torches into precision cutting instruments. Attached quickly — without tools. Neat, clean cuts need little or no grinding or machine finishing. Models to fit all torches, from 70° to 90° types. Cut circles from 1 to 66 inches diameter. Every shop should have these new guides — as basic, time saving tools or as standby equipment.

The new NEECO guides are of three types —for small circles (shown above), for large circles, and for straight lines.

Write for illustrated Bulletin 101 and model selection data.

NEECO *Precision Flame Cutting —Fast and Exact!*

NEW ERA ENGINEERING COMPANY
458 West 29th St., Chicago 16, Illinois



Why You Should Use... PAGE Automatic Welding Wire

• PAGE Automatic Welding Wire is made to rigid specifications which provide consistent characteristics for smooth flow of metal during continuous or intermittent welding. There are many analyses for a wide variety of uses.

for INERT GAS Welding

PAGE Stainless Steel Wire is precision thread-wound on 25-lb. non-returnable convenient reels which fit popular arc welding machines. Six Page-Allegheny grades; wire diameters: .035", .045", .0625".

for SUBMERGED ARC Welding

PAGE stainless, low alloy, and carbon steel wire in layer-wound coils, in 22" or 24" mill coils, or on 200-lb. returnable steel reels. Wire diameters from 1/32" to 5/16"; copper coated if desired.

ACCO *Write to our Monessen, Pennsylvania office for Bulletin DH-402*

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE
Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE Welding Electrodes AND Rods

ALLOYS
All-State
FLUXES

HOW TO DO IT

Condensed Versions of ALL an Operator Needs to Know to Swing to

EASIER WAYS

of Welding, Brazing, Soldering, Tinning, Cutting

FREE!!

Which one do you want?

All-State Welding Alloys Co., Inc., White Plains, N. Y.

I've checked the "How to Use and Apply" folder I want.

All-State

DOC ALLOYS KIT

■ DOC ALLOYS KIT — Generous sampler of 11 torch applied ALL-STATE alloys, 8 fluxes, 1 galvanizing powder.

■ ALUMINUM and ALUMINUM ALLOYS — World's most complete line of aluminum alloys and fluxes — ALL-STATE.

All-State

ALUMINUM

All-State

COPPER

■ COPPER and COPPER-BEARING ALLOYS — 10 ALL-STATE alloys and fluxes for work on copper and copper-bearing alloys.

All-State

STEEL

■ STEEL — 13 ALL-STATE alloys and fluxes for work on STEEL.

Name_____

Address_____

Company_____

PERSONNEL

H. A. Campbell Heads Fatigue Committee

The Resistance Welding Research Committee of the Welding Research Council has appointed H. A. Campbell, Chief, Engineering Laboratories of the Bell Aircraft Corp., as Chairman of the committee to improve the fatigue properties of spot-welded joints subjected to cyclic loading. Endurance limits of spot-welded joints are notoriously low when subjected to cyclic loads regardless of the material joined. A comprehensive program is being prepared at École Polytechnic Institute, Montreal, to bring about improvement in the fatigue properties of such joints. A number of aircraft companies are vitally concerned.

Mr. Campbell has held various positions including Electrical Engineer with the Consolidated Aircraft Co., 1928-39. He then joined the Solar Aircraft Corp. as Manager of the Research Staff, which position he held until 1947. In the following year he served as Aerodynamics Engineer of the Fletcher Aviation Corp. He then became active as Executive Engineer with Frederick Flader, Inc. Since 1950 he has been Chief of the Engineering Laboratories of the Bell Aircraft Corp. He is a member of the AMERICAN WELDING SOCIETY.

Skog Retires

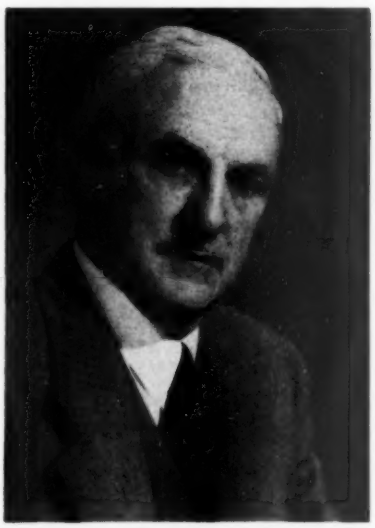
The firm of Sargent & Lundy, Consulting Engineers, 140 S. Dearborn St., Chicago, Ill., announces the retirement of Ludwig Skog, Senior Partner, as of Dec. 31, 1953.

Mr. Skog was born and educated in Norway, receiving his mechanical engineering degree from Trondheim Polytechnic Institute in 1909. He joined the staff of Sargent & Lundy in 1910 and became Senior Partner in 1947.

Mr. Skog is widely known in engineering circles and is considered as one of the most outstanding electric power station design engineers in the country. He is a Fellow of The American Society of Mechanical Engineers, a member of the American Society for Testing Materials, AMERICAN WELDING SOCIETY and has been a member of the Board of the Western Society of Engineers. He is a member of the Board of Trustees of the Illinois Institute of Technology and a member of the Executive Committee of the Armour Research Foundation. He is also a member of the Union League Club, the Chicago Club and the Norwegian Club.

Paton Promoted

W. G. Paton, Vice-President in charge of the Steel Fabricating Division and technical personnel and also Assistant Secretary of the Austin Co., has been elected Secretary. He joined the company in 1919 as a structural engineer.



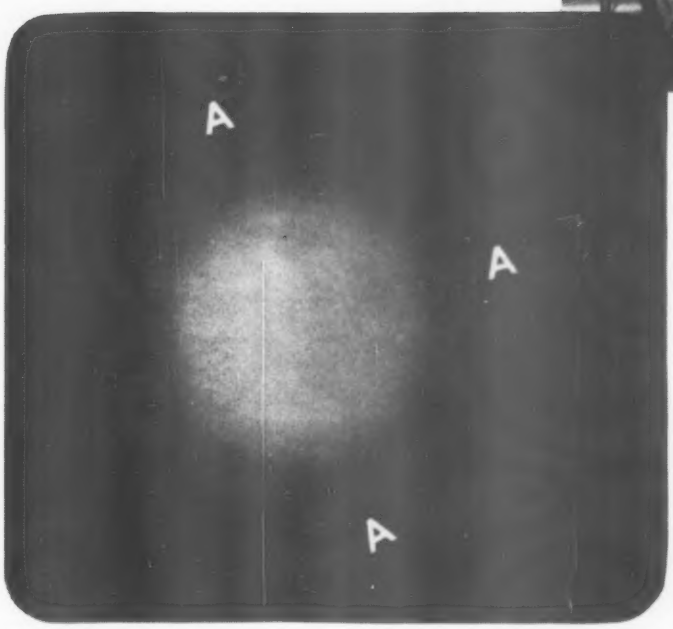
Blackford Appointed General Sales Manager

Progressive Welder Sales Co., 3070 E. Outer Dr., Detroit 34, Mich., announces the appointment of Lester J. Blackford to the position of General Sales Manager. Mr. Blackford has been in charge of the Viking Sales Division.

A graduate of St. Mary's College of Oakland, Calif., Mr. Blackford brings an impressive record of welding experience and Sales Management to his new position.

His world-wide experience includes service as Construction Superintendent of the Anglo-Iranian Oil Co. at Abadan, Iran; Welding Engineer for Kaiser Shipbuilding, Inc., of Portland, Ore.; Hull Superintendent for Ingalls Shipbuilding Co. of Pascagoula, Miss.; Sales Representative for Gibson Welding Supply of Spokane, Wash.; and Sales Manager of Welding Equipment and Supply Co. of Detroit, Mich.

Mr. Blackford is well known in the welding field as a leading authority on all types of arc welding and arc welding fixtures. He is a member of the AMERICAN WELDING SOCIETY and the Engineering Society of Detroit.



Radiograph of repair weld

SAVED...

66⅔% in cost, 75% in time— because

RADIOGRAPHY proved welds sound

Cracks showed up in the shell of this stainless steel sphere. A new one would cost plenty—take priceless time.

But since radiography could prove welds sound and in conformance with code, stainless patches were welded in. The sphere went back to work in one fourth the time and at one third the cost of a new replacement. This is the way radiography helps extend the use of welding and widen opportunities for welders.

Wouldn't you like to know how it can help you increase your business? Get in touch with your x-ray dealer and talk it over.

EASTMAN KODAK COMPANY
X-ray Division, Rochester 4, N. Y.

Radiography—
another important function of photography

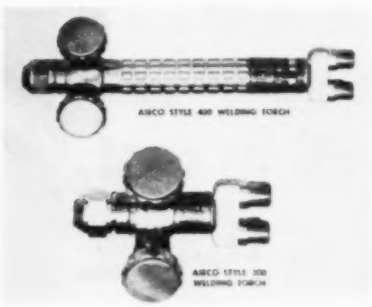
Kodak

NEW PRODUCTS

Airco Torches

Two new Air Reduction torches are now available to industry, the style 400 and the style 300.

The Airco 400 is especially designed for light welding and brazing operations such as automobile bodies, airplane fuselages, kitchen utensils, metal furniture and a host of other light fabrication and repair applications. The Airco 400 is 5¾ in. in length and weighs but 6 oz. A corn-cob handle assures a firm, steady grip. A cutting attachment is available for this torch which quickly adapts it for occasional cutting jobs.



The Airco Style 300 is a compact, lightweight torch designed primarily for oxy-acetylene burning or welding of lead products—sheet, pipe and storage battery parts. It is also suited for jewelry repair work, automobile radiator soldering and light production welding. This torch weighs 5 oz and is 2½ in. in length.

Both torches have ball-type oxygen and acetylene valves which are positioned for easy thumb adjustment and a variety of tips, mixers and extensions are available for these torches. For more detailed information request form ADC 721 by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Manganese-Nickel Steel Welding Electrodes

After years of intensive research and testing, the Stulz-Sickles Co. of 134 Lafayette St., Newark, N. J., has developed the new Flo-Kote, 11 to 13½% manganese-nickel steel welding electrode.

These a-c or d-c welding electrodes run as easily as any mild steel electrode. They are 11 to 13½% manganese-nickel and provide all the advantages of tough, ductile manganese-nickel steel weld deposits. Flo-Kote welding electrodes weld in all positions—overhead, vertical or downhand, and join dissimilar metals.

They eliminate all the special techniques of application required in welding manganese-nickel steel. No peening is necessary.

Flo-Kote can easily be cut with an ordinary oxy-acetylene flame.

Inert Arc Welder

A radically new welder designed to further the advances made with the "sigma" (shielded-inert-gas metal-arc process) by maintaining stable welding conditions regardless of arc variations is this new rectifier type 500-amp 100% duty cycle welder, announced by Miller Electric Manufacturing Co., Appleton, Wis. It consists essentially of closely coupled three-phase transformer, saturable core type three-

phase reactor in the primary circuit, control windings and a selenium rectifier stack. Welding operations are extremely simple. Remote control, using either foot or hand operated unit, is available and provides a wide choice of welder location. Any number of these new "sigma" welders can readily be paralleled to produce greater output. Panel mounted voltmeter and ammeter can be supplied. The rugged rectangular drip-proof cabinet has removable sides and top cover that permit ready access to all parts.

New Tempilstiks

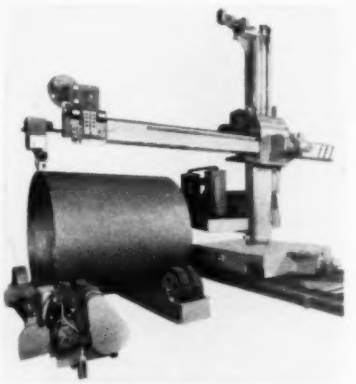
Tempil° Corporation can now supply from stock Tempilstiks° for 425° and 475° F.

Tempilstiks° are now available in the range 113° to 400° F in 12½° intervals, in the range 400° to 500° F in 25° F steps, and in 50° F intervals from 600° to 2000° F.

Welding Head for Automatic Welding

A new type of automatic welder which adapts to a wide range of weldments has been developed by the Pandjiris Weldment Co., St. Louis, Mo.

Called the welding head manipulator, it works as a "robot pilot" which guides the welding head smoothly without manual assistance.



Unlimited maneuverability makes the manipulator easy to adapt to any type of weldment. It may be used in conjunction with all types of turning rolls and positioners.

1. Power car moves up or down track at selected, variable welding speeds. Rapid traverse return.
2. Boom travels in or out at selected, variable welding speeds. Rapid return.
3. Boom moves up and down. Head lowers to floor level.
4. Mast with boom rotates 360° on power car.
5. Welding head swivels 180°.

The operator merely selects the speed, pushes the buttons and watches the gages. It's entirely automatic.

All tachometers, gages and push buttons are mounted together on a central control panel which swings in a 90° arc. Flux dispensing and recovery system and power welding machine are mounted on the mast to prevent snarling of power leads, control circuit cables and flux handling network.

Boom and saddle ride on adjustable, friction-free rollers. Antifriction bearings are used throughout. Precision cone drive primary reduction housings prevent backlash. Power car runs on portable or fixed track sections. Electrical protective devices stop boom and power car at the end of weld seams.

The A. O. Smith *Champion* Heavy-Duty A. C. Welder

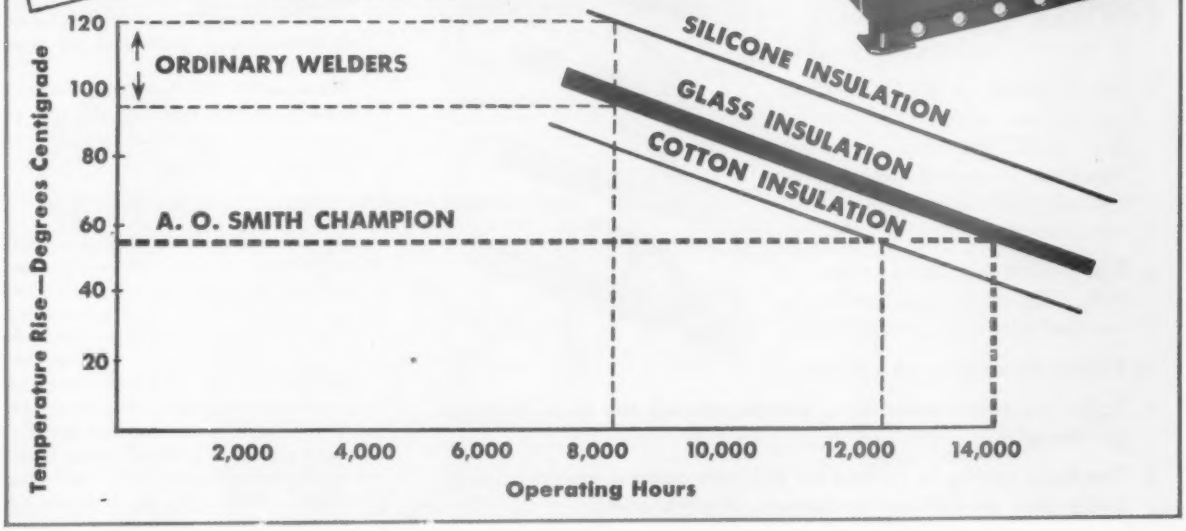
6000 hours longer life

than any other A. C. welder

Available in 300-, 400-, and 500-Amp. models.

PROOF

LIFE EXPECTANCY CHART



Temperature Rise Determines Machine Life

According to the Insulation and Aging versus Temperature Curves, as published by the A.I.E.E. . . . *the cooler a welding machine operates, the longer its production life.*

The A. O. Smith Champion is the *only* A. C. welder on the market with enough copper and cooling capacity to operate without exceeding a 55° C. temperature rise—as compared to the 90° C. rise allowed by N.E.M.A. for glass-insulated welders.

This means: The Champion will give you top production efficiency almost twice as long as any other A. C. welder on the market today.

Built for those who want the best in welding, the Champion has a full 75 open circuit volts, high-velocity down-draft ventilation, all-weather case, 12½ KVA power factor correction and stepless current control.

For additional information on welding machines, electrodes and accessories, see your local A. O. Smith distributor or write to A. O. Smith Corporation, Welding Products Division, Milwaukee 1, Wisconsin.

A.O. Smith

CORPORATION

WELDING PRODUCTS DIVISION

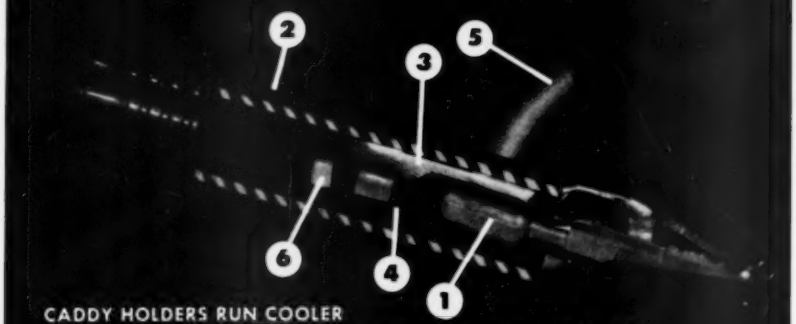
Dept. WJ-853, Milwaukee 1, Wisconsin

INTERNATIONAL DIVISION: MILWAUKEE 1

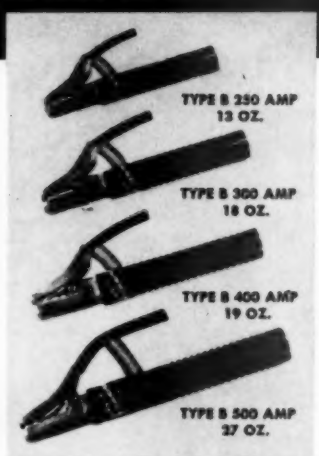
Made by welders . . . for welders

Fully Insulated

NOT ONLY ON THE SURFACE



CADDY HOLDERS RUN COOLER
by going far beyond the regular jaw and tong insulators found on competitive holders to give you the most fully insulated, coolest holder on the market.



COOLER because of 6 major insulation features:

1. The location of the CADWELD connection of the cable to the jaw is 4″ forward from the operator's hand. In other holders it is right under the operator's hand.
2. The operator's hand is over a fully ribbed handle reducing normal contact surface 50%.
3. The body carries no current.
4. Fully insulated cable runs practically all the way through the handle.
5. The tong spring is seated on the non current carrying steel body plus additional insulators at both ends.
6. The cable gripper prevents the cable from flexing or pulling out at the weld.

CONNECTED BY THE CADWELD PROCESS

CADDY®
ARC WELDING ACCESSORY DIV.

ERICO PRODUCTS, Inc.
2070 E. 61st PLACE
CLEVELAND 3, OHIO

The "manipulator" is available in standard models (on power cars or fixed base)—with vertical boom travel from floor level to 24 ft—longitudinal boom travel up to 30 ft.

Further information may be obtained by writing The Pandjiris Weldment Co., St. Louis, Mo.

Electrode Doubles Welding Speed

Air Reduction has just announced the availability of a new type welding electrode based on a principle that is different than any other commercially available electrode. This new electrode, known as Airco "Easyare 12," is for welding mild steel at speeds doubling those obtained with conventional electrodes.

The tremendous increase in speed is achieved through the addition of a large amount of powdered metal to the electrode coating. The powdered metal changes the arc action so that welds can be made by dragging the electrode in contact with the plate. Because the metal powder becomes part of the weld bead, faster welding is achieved. Weld spatter is decreased to less than half that obtained with regular electrodes.

The weld beads are exceptionally smooth and the weld metal is of high strength, good ductility and excellent X-ray soundness.

Airco "Easyare 12" is recommended for the fabrication of mild steel involving plate and rolled sections.

For complete details on this electrode request a copy of bulletin ADC 650, by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Aluminum Welding Rod

A new, specially coated, rod announced by All-State Welding Alloys Co., Inc., 249-55 Ferris Avenue, this city, is for both carbon arc and torch welding aluminum.

The new rod is designed specifically for work on aluminum types 3S, 14S, 43S, 52S, 53S and 61S. It's field testing has focussed primarily upon the general fabrication of these types, and the gamut of end products has included tanks, shapes and containers, as well as light gauge joining involving butt, lap, edge and corner work.

User benefits noted are: (*a*) increased speed of application without any sacrifice of physical properties, (*b*) sound, porosity-free welds of good appearance, (*c*) less distortion of work, and (*d*) flexibility in choice of carbon arc or torch.

The new product is to be marketed as All-State No. 35 F. C. Aluminum Rod (flux coated). Diameters are 3/32, 1/8, 5/32 and 3/16 inch. Length, all sizes, is 28 inches. Standard 5-lb convenience packages with the rod wrapped in wax paper, as well as the rod in bulk will be available through some 700 All-State Distributors.

Magnetic? OR Electronic? WELDER CONTROL — WHICH WILL DO YOUR JOB BEST?

Square D makes them all... for simplest or most exacting applications!

Magnetic

for General Purpose Machines

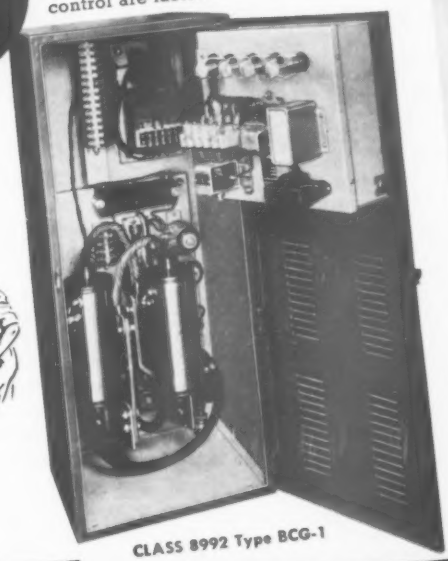
For applications requiring widely varying welding conditions, normal welding speeds and maximum simplicity.

CLASS 8992 Type BBG-1

Electronic

for High Speed Welding

For production line (gun or stationary) welders and other applications where high speed, high currents or dual gun control are factors.



CLASS 8992 Type BCG-1

Electronic (SYNCHRONOUS)

for Precision Welding

For welding aluminum, other non-ferrous and ferrous metals requiring precision weld times; stepless heat control; slope or taper control.

CLASS 8993 Type BDG-2

You'll find your nearby **Square D Field Engineer** *a source of sound counsel in selecting the welder control best suited to your application.*

SQUARE D COMPANY

WELDING ARCS NEWS

New G-E Fillerarc Equipment Widely Acclaimed by Industry

Dependable, low-cost operation and wider application praised in new consumable electrode gas-shielded welding equipment

Demand for new G-E Fillerarc equipment for consumable electrode gas-shielded welding is the greatest in G-E Welding history. At the Metals Show, at G-E Distributor demonstrations, and in customer plants, Fillerarc equipment has proved its merit as the leading equipment for this high-speed process.

BURN-BACK AND STUBBING MINIMIZED

Of course customers are amazed by the high speeds of Fillerarc equipment and by how fast operators pick up Fillerarc technique. But their greatest praise is for reduction of burn-back and stubbing problems which plagued operators of other equipment.

WELDER, GUN, WIRE-DRIVE FORM PACKAGE

Ease of operation and minimum trouble are built-in features of new Fillerarc equipment. Here's why:

Fillerarc Welder has a self-regulating generator with a rising volt-ampere characteristic which maintains desired arc length automatically. What's more, you can change wire speed even while you are welding and the current is always right.

Fillerarc Gun pulls wire into gun, permitting the use of smaller wire. Result: you can weld thinner sections than ever before possible.

Fillerarc Wire-drive is powered by a Thy-mo-trol* drive and dynamically braked to give you precise wire-feed control. Dial gives continuous wire-speed indication—no need to time and measure.

If you haven't yet seen Fillerarc equipment in action, contact your G-E Welding Distributor today. He can give you full data and arrange a demonstration. He's listed here and in the yellow pages of your phone book under "Welding Equipment—General Electric." General Electric Co., Schenectady 5, N.Y.

*Reg. Trade-mark of General Electric Company

710-15

***P. S.:** Your G-E Welding Distributor can furnish filler wire for this process. Ask him for a quotation to your specifications.*

ACCESSORIES

Now—a Plastic Ventilated Helmet

The famous G-E ventilated helmet is now available in plastic to give you the last word in comfort, convenience, and long life.

FOR YOUR COMFORT

- G.E.'s famous ventilated design provides a cool head on the job.
- Moisture-proof headgear assumes head shape exactly—but won't warp.
- Ratchet-type device makes exact head-size adjustment simple.
- New four-position stop meets vertical and overhead needs, too.

FOR LONG LIFE

- Seamless plastic construction has excellent strength.
- Plastic shell is moisture-proof and heat-resistant.

Avoid fatigue, get real comfort and convenience on the job with the new G-E plastic ventilated helmet—lift-front or stationary type.

ELECTRODES

Columbia Iron Works Selects W-612A

In choosing an electrode for shop-welding structural roof joists, Columbia Iron Works of St. Louis was looking for the best available combination of weld quality, speed, and usability.

After tests, they selected G-E Type W-612A electrodes as tops for this job. Columbia is mighty pleased with the results, too, because W-612A helped them complete delivery in 20% less time than originally estimated.

This successful application of W-612A—one of more than 70 arc-welding electrodes supplied by G.E.—is another example of "balanced electrode design for best over-all results."

You'll Find the Best Electrode for Your Job in the G-E Line—Most Complete in the Industry

G-E WELDING DISTRIBUTORS

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo, Sterling—Hendrie & Bolthoff

Connecticut: Hartford, New Haven—Harris Sales & Service

Florida: Hollywood—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Hutchinson—Kopper Supply

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co., Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Hereford—Tex-Air Gas; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Alaska: Anchorage—Northern Supply

Canada: Tornoto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

GENERAL ELECTRIC

the Waterman

WIDE BAND

POCKETSCOPE®

MODEL S-14-B

Size:
12" x 6" x 7"
14 Pounds

ANOTHER EXAMPLE OF Waterman PIONEERING...

The WIDE BAND POCKETSCOPE, model S-14-B, hits a new high in frequency response for light, compact, truly portable oscilloscopes. The response extends all the way from DC to 700 KC within —2 db without peaking. Thus providing a pulse rise time of 1.8 microseconds. Furthermore, sensitivity has not been unduly compromised in order to accomplish such fidelity. The vertical sensitivity is 50 millivolts rms/inch. The sweep is operated in either a repetitive or trigger mode and covers a range from 0.5 cycles to 50 KC with synchronization polarity optional. Other essential vertical and horizontal amplifier characteristics include non-frequency discriminating attenuators and gain controls as well as individual calibration voltages. Additional provisions for direct access to all the deflection plates, the second anode, and the amplifier outputs help to make the S-14-B a standout instrument of flexibility and utility. All this plus portability! The incredibly small size and light weight of the S-14-B now permits "on-the-spot" use of the oscilloscope in all industrial, medical, and communications fields. Its rugged construction assures "laboratory performance" regardless of environment.

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PHILADELPHIA 25, PA.

CABLE ADDRESS: POKETSCOPE

WATERMAN PRODUCTS INCLUDE

S-4-A	SAR	PULSESCOPE®
S-5-A	LAB	PULSESCOPE
S-11-A	INDUSTRIAL	POCKETSCOPE
S-12-B	JANized	RAKSCOPE®
S-14-A	HIGH GAIN	POCKETSCOPE
S-15-A	TWIN TUBE	POCKETSCOPE

MEMO... Write for details today!

WATERMAN PRODUCTS

Also RAYONIC® Cathode Ray Tubes and Other Associated Equipment

A-C Arc Welder

The Shober Sales, Inc., 900 W. Weber Ave., Stockton, Calif., have put out a small welder for shop and portable use. It is claimed that this welder performs in all positions, flat, vertical and overhead, on 110- or 220-v connection. Necessary accessories are included. It weighs 77 lb and is well constructed.

Phos-Trode Bare, Coiled Wire

Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis., has developed a specially processed phosphor bronze (Grade A) bare, coiled wire for use with the inert-gas consumable electrode process.

Its primary use is for overlay applications since it is a good, soft bearing alloy. However, Phos-Trode bare, coiled wire can also be used for joining brasses, tin bronzes, cast iron, etc., giving exceptionally sound welds with the inert-gas process.

This new product is available in 0.045-, $^1/_{16}$-, $^5/_{64}$- and $^3/_{32}$-in. diam sizes, layer wound on either spools or rims in 25-lb standard packages.

It may be used with the Aircomatic, Linde Sigma and General Electric filler-arc equipment.

Electrode Holder

A 400-amp manual electrode holder that features new design has just been announced by Tweco Products Co., Wichita, Kan.

The new Twecotong "Rod-Rated" Model A-516 Air-Way holder was developed to meet the growing demand for a lightweight, high amperage tool. The A-516 weighs just 27 oz. As its Rod-Rated model number indicates, the Twecotong A-516 is designed to handle electrodes through $^5/_{16}$ in. It will hold rods as small as $^3/_{32}$ in. diam.

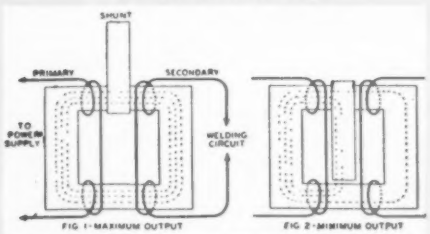
Departing from conventional design, this holder features air vents between the holder castings and the insulation. On higher amperage work this allows the heat from the arc, which is absorbed by the castings, to be dispelled through the ventilating ducts between the casting and the insulators.

To keep the holder cool it is supplied with a large diameter handle that has only point contact with the holder casting, permitting a free flow of cooling air. The new wedge-shaped upper jaw provides maximum pressure with minimum contact area for a cooler running holder.

As in all other Twecotongs this new model is supplied with patented "Super-Mel" laminated glass cloth insulation that resists extreme heat and impact.

Outstanding Before... Even Better Now

The exclusive Sureweld four-coil transformer design



The heart of the Sureweld is an exclusive 4 coil transformer that provides "long" inductive coupling, high inherent reactance, and uniformly fine welding performance. A movable core section provides stepless current control.

Sureweld® A-C SHOP WELDER IMPROVED IN MANY WAYS

The Sureweld A-C Shop Welder, for general utility welding, has always been outstanding for the remarkable arc stability it has provided, the desirable welding characteristics at all current levels and the operator's control of current value.

And now this welder has been greatly improved. The exclusive, patented 4 coil transformer has been positioned horizontally for even better ventilation and cool operation even with higher output. Primary and secondary windings are double glass-insulated (Class B) magnet wire providing higher dielectric for peak performance at high heats. Operator's convenience has been increased by side-mounting the control handle next to the high-visibility calibrated scale. Other advances markedly decrease KVA input and increase ease of operation, dependability and portability. Best of all, the improved design has resulted in lower prices.

We'd like to send you our new bulletin describing the improved Sureweld Shop Welder in more detail, or demonstrate the welder conclusively in your own shop. Available in Model S-18C, range 20 to 180 amps., and Models S-30 and S-30C, range 25 to 295 amps. Use the handy coupon now.

NATIONAL CYLINDER GAS COMPANY

840 N. Michigan Avenue, Chicago 11, Illinois

Branches and Dealers from Coast to Coast

NCG®

EVERYTHING FOR WELDING

WRITE TODAY

National Cylinder Gas Company, J
840 N. Michigan Ave., Chicago 11, Ill.

☐ **Send me Bulletin NH-101 on the new Sureweld Shop Welders, for general utility welding, described above.**

☐ **Send me information on the Sureweld heavy-duty Industrial Welders for production welding.**

NAME_____ POSITION_____

FIRM_____

ADDRESS_____

CITY_____ ZONE____ STATE_____

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington 25 D. C.

2,659,966—Method of Fabricating Welded Girth Joints—James Coryell Turnbull, Oakmont, Pa., assignor to Scaife, Co., Oakmont, Pa., a corporation of Pennsylvania.

This method relates to the welding together of two generally tubular metal elements of the same cross-sectional shape and dimensions wherein at least one of the elements has a flange formed at its end extending endwise of the element at an acute angle to the wall of the element adjacent the flange. The elements are assembled end to end with the flange in engagement with the other element at a portion of the flange removed from the extremity thereof so as to center the elements relative to each other and permit free escape of gases formed during the welding operation. The elements are then fused together in longitudinal alignment so that the welded joint and the elements ultimately are all in longitudinal alignment.

2,660,141—Welding Vise—James G. Thomas, Cleveland, Ohio.

This patent covers a specialized welding vise having two angularly related fixed jaws and spring retractable jaws provided in the vise.

2,660,654—Timing and Sequencing Circuit—Joseph J. Riley and Richard Alm, Warren, Ohio, assignors to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

This patent relates to a control circuit for electric resistance welding apparatus wherein a weld contactor is provided and is adapted to control the flow of weld current. A specialized electronic circuit is connected to a source of pulsating power for energization of the weld contactor during predetermined circuit conduction conditions.

2,660,655—Walking Welder—Edward R. Powell, North Plainfield, N. J., assignor to Johns-Manville Corp., New York, N. Y., a corporation of New York.

Powell's patent relates to welding apparatus including an electrode having an end portion disposed for contact with a work surface to be welded and a foot member adjacent the electrode and movable relative thereto over a path having components extending substantially perpendicular to and parallel with the surface. Other means are provided for moving the foot member into and out of contact with the surface so that the generally perpendicular component of movement is of sufficient length to lift the electrode from contact with the work surface.

2,661,416—Welding Head for Simultaneously Effecting a Series of Spot Welds According to the Double Spot Method—Kuno Eisenburger, Wels, Austria, assignor to EVG Entwicklungs- und Verwertungsgesellschaft m. b. H., Graz, Styria, Austria.

This specialized weld head comprises at least two plate-shaped electrode holders arranged side by side in a common plane and having projections arranged on the edges of the plates facing one another. These projections intermesh with one another in gear teeth fashion and leave an insulating gap between adjacent projections. These projections serve as weld electrodes.

2,661,428—Transportable Welding Apparatus—Karl Joel Aversten, Lidingo, Sweden, assignor to Svenska Aktiebolaget Gasaccumulator, Lidingo, near Stockholm, Sweden, a corporation of Sweden.

The apparatus of this patent includes an engine, an electric generator driven by the engine and an electric battery connected to the generator and to a welding device through a current regulator. Other means are present for automatically adjusting the current regulator in response to the battery current.

2,661,599—Pneumatically Operated Welder Head Construction—Frank Frederick Folmer, Detroit, Mich.

Folmer's patent covers a specialized welder head of the type indicated.

2,662,153—Method and Device for Welding Wires on Metal Bodies—Ulrich Gunther, Domat (ems), Switzerland, assignor to Inventa A. G. fur Forschung und Patentverwertung, Zurich, Switzerland.

In this patent, a process for welding thin wires to a small metal pole supporting bodies is disclosed and the bodies are initially arranged in a circle closely to, but insulated from one another. The bodies have two poles and a welding electrode is disposed above the circle and in fixed relationship to a spot below the electrode but vertically movable with relation thereto. Switch means connect to only one of the poles exactly underneath the welding electrode leaving the other pole unconnected. The wire is made to meet the circle at a tangent at the spot below the electrode and a switch is actuated for welding when the pole and the electrode are in opposite positions.

2,662,959—Electronic Sequence Control for Intermittent Operation of Rotary Electrode Welding Apparatus—Joseph J. Riley and Richard Alm, Warren, Ohio, assignors to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

This patent relates to a sequence control circuit for use with electric resistance welding apparatus of the type adapted to perform a plurality of spaced welds in controlled time sequence. The circuit includes actuating means for effecting indexing movement of welding electrodes between succeeding welds and where the magnitude of the indexing movement may be adjusted. A weld contactor is provided and has means to time the duration of the weld whereas energizing means for the weld contactor are provided and a control device is present in the circuit for the actuating means. The energizing means include adjustable time delay means for energizing the contactor a predetermined time after the control device operates. Control means are provided for operating the control device to cause indexing movement of the electrodes between succeeding weld operations.

2,663,075—Method of Welding Turbine Rotors—George Edwin Linnert, Baltimore, Md., assignor to Armco Steel Corp., a corporation of Ohio.

This method of welding turbine elements includes providing a support for turbine blades and disposing along the support at the approximate relative positions desired a plurality of blades having base portions of such size as to be consumed in

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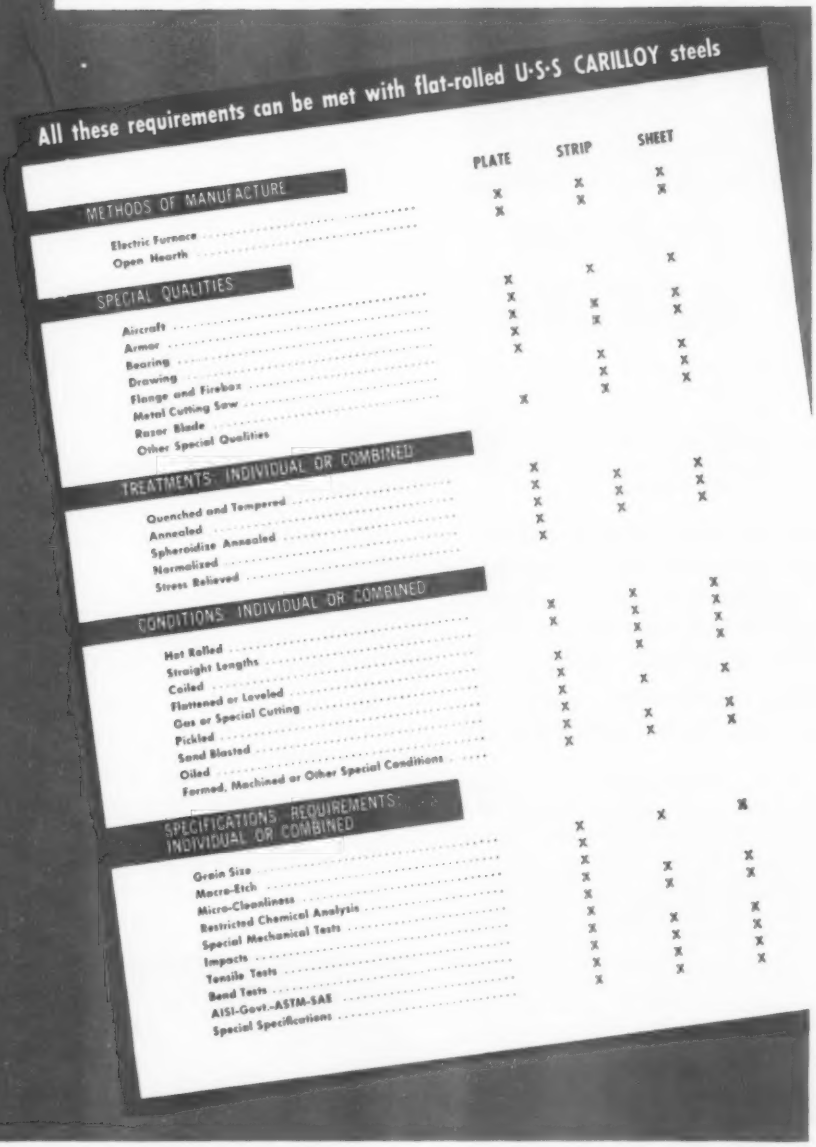

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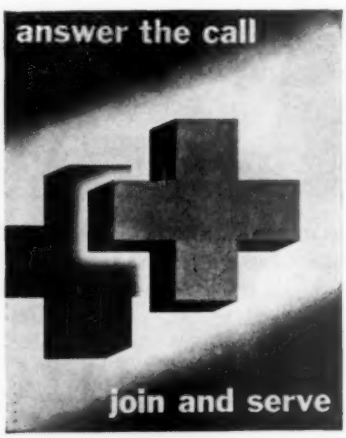
welding. Outermost limits of fayed edges of the blades are blocked off and welded joints are formed between the blades themselves and between blades and the support by fusing bottom surfaces of the blade bases while depositing weld metal to fill the spaces between adjacent blade bases.

2,663,783—Wrinkle Type Replaceable Cap for Welding Electrodes—William G. Fetter, Arthur F. Wood and Edman F. Holt, Indianapolis, Ind., assignors to P. R. Mallory & Co., Inc., Indianapolis, Ind., a corporation of Delaware.

This welding electrode includes a hollow welding tip with a shank portion. The shank has a determined taper and an angulated outer lead end surface. A cap structure comprising a welding face and a leading edge is aligned with and positioned extending into the shank. This cap has a skirt portion with a taper adapted to mate with the taper of the shank and includes a series of angular rings that adjustably fit into the shank and are resilient so as to afford a releasable tight grip between the cap and shank but at the same time avoiding seizure between the surfaces thereof.

2,663,784—Means and Method of Making Metal Strip—Lorenz Iversen, Pittsburgh, Pa., assignor to Mesta Machine Co., Pittsburgh, Pa., a corporation of Pennsylvania.

Iversen's method relates to a formation of a continuous length of strip steel from a plurality of end-to-end strips and comprises trimming the ends of a pair of steel strips and overlapping the trimmed ends. Welding current is passed through the overlapped ends progressively along the width of the strips while simultaneously the welded joint is rolled down as it fuses flush with the adjacent unwelded strip ends.



SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Fillerarc Welding

Boston, Mass.—The December dinner meeting of the *Boston* Section was held on Monday, December 14th, at the Westinghouse Auditorium.

As coffee speaker, Capt. Francis G. Wilson of the Homicide Squad, Boston Police Headquarters, entertained 143 members and guests by explaining the operation of a big city homicide squad, illustrating with numerous anecdotes, including the solution of a murder that took place only the week before.

The technical speaker, R. W. Tuthill AWS of the General Electric Co., Fitchburg, Mass., gave a very interesting talk on GE's new process of Fillerarc Welding, explaining the arc characteristics and also the generator characteristics required to make the process work in a practical manner.

Christmas Party

Bridgeport, Conn.—One hundred members and guests of the *Bridgeport* Section had a most enjoyable time at the Christmas party held on December 5th at the Black Horse Inn, Orange, Conn.

Resistance Welding

Buffalo, N. Y.—Two speakers were featured at the December 3rd dinner meeting of the *Niagara Frontier* Section. The first speaker, Frank Rowe of the Federal Tool and Engineering Co., led off with a 30-minute talk on "Resistance Welding, Applications and Controls." The particular application dwelt on during this informative talk, was the welding of very small and minute parts for the radio and television industry. For most of the membership it was a revelation to hear that a wire 0.006 in. thick could be welded to a nickel tube 0.002 in. in diameter. Slides were shown of many more instances of resistance welding of very small assemblies.

Stuart C. Rockafellow AWS (Robotron Co.) followed Mr. Rowe with a 30-minute talk on the fundamentals of electronics. As Mr. Rockafellow put it, "A Four-Year College Course in Electronics in Thirty Minutes." To many of the members it was by far one of the most informative talks ever heard at a Section meeting. For the first time, many understood the part the electronic tube and timing devices play in the operation of resistance welding equipment.

A brisk question and answer period seemed to substantiate the appreciative attitude of the membership.

Preview of Progress

Chicago, Ill.—The December meeting of the *Chicago* Section, held on the 11th, was the first meeting of the year when sociability reigns and welding as a subject is set aside. The meeting opened with a cocktail hour followed by dinner. The coffee speaker, Don Kolloway, former major league infielder, discussed many amusing incidents in his 12½ years of experience.

Following dinner General Motors presented their "Preview of Progress" which is a stage presentation of scientific progress. Artificial rubber was produced by mixing two chemicals in a bottle. Another demonstration was using a bottle as a hammer and driving a spike through a two by four plank, yet a small substance, less than the size of a pencil eraser, dropped inside the bottle caused it to burst into fragments. Jet propulsion was explained and demonstrated. This was an excellent presentation and was amusing and enjoyable.

The balance of the evening was spent in a sociable get-together.

Plant Tour

Chicago, Ill.—The *Chicago* Section, deviating from their policy of many years standing, toured the Hotpoint Co.'s new refrigerator manufacturing plant on the afternoon of Friday, November 20th. There was a question in the minds of the program committee when arrangements were made, as the tour had to be on an afternoon and completed by 4 P.M. as the line was closed down.

Much to everyone's surprise 128 turned out and saw the new plant and modern lines of production peculiar to refrigeration production. To the welding-minded person the feature was the forming from a single sheet and through a number of operations completely welding the container without removing it from the giant press. Arc welding, resistance welding and gas welding were utilized at various points in the production line each to its advantage.

The production-minded guest was amazed at the utilization of the air rights in the factory. The factory was a complete mass of conveyors located high against the ceiling out of the way of floor traffic. In fact, floor traffic of parts was practically nil.

Following the plant tour a movie "Design of Tomorrow" was shown to the group in the auditorium.

Joe Kashuba, Foreman of Range Assembly, explained the "Foreman's Golden Rule Book." He brought out that while the factory is in a sense a giant machine, the employees, each to his function, is not a machine but a personality and is so treated with consideration and friendliness.

Fred Tarleton, Manager of Refrigeration Engineering, then spoke in a most interesting manner about the problems of manufacturing a product such as theirs that carries a 5-year warranty of operation. He explained that 5-years is not the limit of their sights but a lifetime is the continual aim. Mr. Tarleton emphasized that costs were important, speed of production and many other things, but that above all of these there stood one important point that must not be lost sight of if long life was to be expected. That point was cleanliness. With passageways much less than the diameter of a human hair there must not be any scale or foreign matter. It can well be expected that this point offered problems to those who specified welding.

Thomas H. Swisher AWS of the Hotpoint Co. organization and Chairman of the Chicago Section, had so carefully planned this tour that it went along smoothly without a hitch and yet everyone had time to see that which they were interested in, ask questions and receive answers. The tour was made in groups of about 20, each with a leader. The leaders were courteous beyond expectation.

It was a most pleasant and enlightening meeting.

Welding Titanium Alloys

Cincinnati, Ohio.—An excellent research paper on "Welding of Titanium Alloys" was presented by C. B. Voldrich AWS of Battelle Memorial Institute at the November 24th meeting of the *Cincinnati* Section held in the Engineer and Scientist Building. Mr. Voldrich's talk was illustrated with slides.

Distortion in Welding

Cleveland, Ohio.—One of the finest talks on the subject "Control of Distortion in Welding" was given by J. R. Stitt AWS of the R. C. Mahon Co., Detroit,

Speaker J. R. Stitt and Lewis Gilbert, Cleveland Section Chairman

at the December 9th dinner meeting of the *Cleveland* Section held at the Allerton Hotel. Mr. Stitt's talk was exemplified by means of oxy-acetylene flame and its effects in straightening members which had been distorted due to impact or improper handling of materials.

Slides were used to show various heavy structural members which had been distorted. The slides also showed the progressive procedure in straightening by means of heat applications, pointing out the zones which were heated and their sequence of heating to effect proper straightening.

In a very nontechnical dissertation Mr. Stitt pointed out the various physical changes that take place during heating and compared same with the cold working of steels without the application of heat.

Slides also disclosed many ingenious methods and types of applications for straightening various members which, for all practical purposes, would normally be scrap.

Coffee speaker was a department store Santa Claus, Jack Kelley, who told some interesting stories of children's reactions at this time of year.

Aeronautical Research

Columbus, Ohio.—A joint dinner meeting of the *Columbus* Section and the Columbus Technical Council was held on November 12th at the Seneca Hotel. Dr. John F. Victory of the National Advisory Committee for Aeronautics told the story of the early history of aeronautical research. He emphasized personalities and incidents that were very interesting.

Austenitic Stainless Steels

Columbus, Ohio.—On December 11th, Nicholas C. Jessen AWS, Babcock and Wilcox Co., Barberton, Ohio, talked to the *Columbus* Section on "The Welding of Austenitic Stainless Steels" at a dinner meeting. Mr. Jessen is very familar with the welding and metallurgical problems of pressure vessel fabrication. His talk was well received by more than 50 dinner guests and others who came for the technical session of the evening. Mr. Jessen illustrated his talk with slides showing the effects of wrong choice of stainless welding wire or rods and clearly showed that careful selection of electrodes for the application was necessary for sound welding.

The technical session was preceded by a film titled "The Handwritten Word" furnished by Movies, USA.

Plant Visit

Dallas, Tex.—On November 18th, 40 members of the *Dallas* Section, following dinner at the Lennox Hotel in Grand Prairie, took part in a tour conducted by Chance Vought Aircraft Co. through their plant to see their latest welding methods, procedures and welding fixtures in application.

Quiz Program

Dayton, Ohio.—A quiz program with panel on "Inert Gas Welding Processes" was held by the *Dayton* Section on Tuesday, December 8th, at the Dayton Engineers' Club. The panel consisted of: Robert E. Bowman AWS Wright Air Development Center; Robert C. Appenzeller AWS, Delco Products Division, GMC; William E. Dundon AWS, Huffman Manufacturing Co.; C. A. Heffernon AWS, Linde Air Products,

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The Chicago Bridge and Iron Company used ARCAIR Torches to gouge out defective welds during construction of the two million dollar Hortonsphere near West Milton, N. Y.

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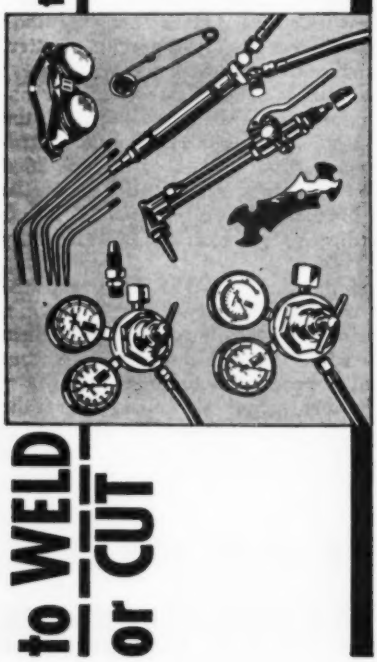

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Indianapolis; L. P. Marking AWS, and J. W. Hall AWS, Panel Chairman.

Everyone present was given a multiple choice quiz on the subject at the beginning of the meeting. After these were completed, the panel of experts discussed the correct answers to each question. The two members of the audience with the highest number of correct answers were each awarded a "Troyloafer" reclining chair.

A sound color film entitled "Tool of Many Uses" covering the various applications of the Aircomatic process in manual and automatic welding was shown through the courtesy of Airco.

Program Schedule

Dayton, Ohio.—The following is a program schedule for the *Dayton* Section for the remainder of the 1953–54 season:

Mar. 9—"High Production Applications of Resistance Welding," Clarence Schultheis

Apr. 13—"Tooling for Automatic Welding," Anthony K. Pandjiris AWS

May 11—Plant Visitation (to be announced)

June 8—Annual Picnic

Meetings will be held at 8:00 P.M. in the Dayton Engineer's Club, 112 E. Monument Ave., unless shown otherwise.

Ladies Night

Denver, Colo.—The Annual Ladies Night was held by the *Colorado* Section on December 8th in the Festival Room of the Oxford Hotel with an attendance of 54 members and guests. Jesse E. Williams of the U. S. Bureau of Public Roads, who was assigned by the Government to a mission of assistance to Turkey under the Federal Aid Highway Program, along with his wife, gave a very interesting talk on "Life in Turkey" which was followed by questions for over a half hour. Some of the welding problems Mr. Williams came across while on his trip were also discussed.

A Walt Disney film entitled "Seal Island" was shown through the courtesy of the Ideal Pictures Co.

Plant Visit

Des Moines, Iowa.—For its November meeting held on the 19th, the *Iowa* Section visited the Armstrong Rubber Manufacturing Plant, Des Moines.

Following a most delectable and tasty dinner served in the plant cafeteria, groups of seven or eight were formed and guided from beginning to end of the tire manufacturing process. All sizes of tires were being produced from the small trailer type through huge truck sizes. Each could be observed in every phase necessary for its assembly.

From chunks of crude rubber combined with sulfur and carbon-black ingredients along with fabric, high-tensile steel wire, emerges the finished tire product. The vast quantities of equipment, the immense floor area on several levels and the strange names of machines or the processes were of great interest. The agility of the operator in assembling the plys, casing and beads was of particular interest to many.

At the gathering of the various groups following the tour, Mr. Robinson of Armstrong's Industrial Relations Department answered a multitude of questions.

Safety in Welding

Detroit, Mich.—Three speakers were scheduled for the November dinner meeting of the *Detroit* Section, held at the Engineering Society of Detroit, with an attendance of 106. The subject covered was "Safety in All Phases of Welding." The speakers were Ray Harvey, Director of Safety, Murray Corporation of America, Carl Peterson, Staff Safety Engineer, Chrysler Corp., Jim Lake, Michigan Mutual Liability Insurance Co.

Coffee speaker was Hale A. Clark, Vice-President of Sales with the Consolidated Gas Co. Mr. Clark talked on "What's New in Gas."

Stag Social Evening

Detroit, Mich.—A stag social evening for members only was held on Friday, December 11th, by the *Detroit* Section at the Henry Ford Trade School Alumni Club in Royal Oak. During the meeting a film entitled "Realm of the Wild" was shown through the courtesy of *Outdoor Life*. Ninety-one members had a most enjoyable time.

Plant Tour

Grand Rapids, Mich.—On November 23rd, 98 members and guests of the *Western Michigan* Section, after partaking of a very tasty smorgasbord at the Harris Hotel in Kalamazoo, made a tour of the Ingersoll Steel Products plant where Army and Navy amphibious tanks are being manufactured.

Job Shop Practices

Grand Rapids, Mich.—L. C. Monroe AWS, publisher of *Welders Digest* of La Porte, Ind., discussed the subject "Job Shop Practice and Maintenance Welding in Shops" at the December 21st meeting of the *Western Michigan* Section held in the Varsity Grill.

Coffee speaker was J. Leslie Livingston, local insurance man and sportsman, who showed pictures of his recent hunting trip in Wyoming where he bagged an antelope, an elk and a deer.

Ladies Night

Indianapolis, Ind.—The *Indiana* Section

had its annual Ladies Night on Friday evening, December 11th. Sixty adults were present at Linder's Restaurant, south of Anderson. A smorgasbord dinner was followed by entertainment in three parts.

The first part was a stage presentation "Engineering, the Key to Progress." This was a performance covering recent developments in science and industry by Delco-Remy Division of General Motors.

The second part was a motion picture of a boat trip through the Grand Canyon. The film was narrated by Moulton Fulmer who took the pictures as he made this hazardous journey.

The finale was the drawing for the door prizes.

Ladies Night

Kansas City, Mo.—The December meeting of the *Kansas City* Section held on the 10th at Fred Harvey's Pine Room was in honor of the ladies. There were over 30 present for the dinner.

Vice-Chairman George Demecs presented Ed Dato, Vice-President, District No. 6, with a gift in appreciation for the service Ed has given to this Section. Ed is being transferred to the New York area.

Speaker for the evening was Hugh Johnson, Special Agent for the FBI, Kansas City district. Mr. Johnson gave a very interesting talk entitled "Your FBI." In his talk he outlined the functions and responsibilities of their organization.

Nondestructive Inspection

Louisville, Ky.—The December 1st dinner meeting of the *Louisville* Section was held at Korfage's Tavern.

An illustrated talk on "Nondestructive Inspection of Welds" was given by Lloyd J. Oye, District Sales Manager, Magnaflux Corp., Chicago. Mr. Oye covered the use of metal particle, fluorescent light, and die penetrant methods of testing welds, indicating that all three have their own particular field with the possibility of a slight overlapping. He placed particular emphasis on the use of these inspection methods prior to final inspection so that the use of these methods would effect a saving in production. He showed by slides numerous applications for these testing methods.

Coffee speaker was Lt. Forest E. Hurst of the Fire Prevention Bureau who gave an excellent talk on fire prevention in industry.

Welding Metallurgy

Milwaukee, Wis.—The November 20th meeting of the *Milwaukee* Section was held at the Ambassador Hotel with approximately 100 members and guests in attendance.

Immediately following dinner, Lt. Michael Wolke, Director of Youth Aid Bureau for Milwaukee, gave a very interesting coffee talk on the topic "Juvenile Delinquency" which was a very timely subject resulting in a lively discussion of the points covered.

Chairman Werner Gallo introduced the technical speaker, Dr. Samuel L. Hoyt, AWS, Consultant with Battelle Memorial Institute, who spoke on the subject "Welding Metallurgy." A recognized authority on the subject, Dr. Hoyt centered his talk around the very controversial subject "Weldability of Steel" pointing up the fact that in the past we have not attacked the problem of weldability on a sound scientific basis. In fact, according to him, we do not even have a good definition for weldability. He cleverly worked in such investigation reports as those on the failure of the S. S. Schenectady and the Three River Bridge failures to support his contentions that, generally, we use the wrong approach in our scientific investigations on most welding problems. He also ably presented his philosophy of scientific attack on a problem to solve the problem.

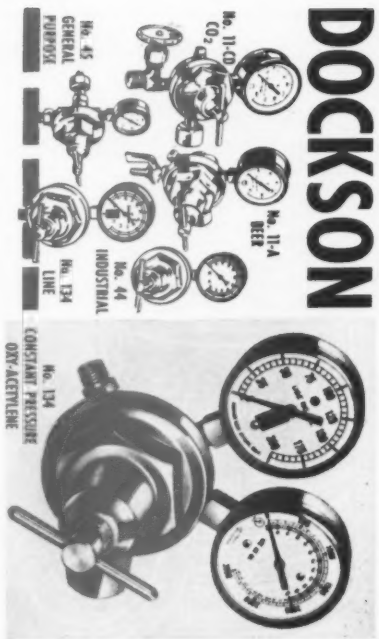
Welded Structures

New York, N. Y.—On Dec. 14, 1953, a joint meeting of the Metropolitan Section of the Society for Non-Destructive Testing and the *New York* Section of the AMERICAN WELDING SOCIETY was held, with S. Baum AWS Welding Engineer at the Philadelphia Naval Shipyard, as technical speaker. His excellent subject, "Welded Structures—Acceptability and Intended Use," was well received by the members of both sections and their guests. Mr. Baum outlined the advancements made in welding at the Philadelphia Naval Shipyard, as well as the types of nondestructive tests used to substantiate weld quality. An interesting number of slides showed the radiographic quality standards presently in use for naval ship work.

The program was preceded by dinner at Schwartz's Restaurant, 54 Broad St., New York City, where the New York Section's meetings are regularly held.

Round-Table Discussion

Olean, N. Y.—A round-table discussion on "What Practical Approach Should Engineering Set Up in the Basic Design and Detailed Drawings of Weld Fabrications to Govern Quality" was the feature of the November 23rd meeting of the *Olean-Bradford* Section held at the Castle. The discussion was led by Henry Bender AWS, and Herbert Rogers AWS of Clark Brothers Co. The discussion was followed by Charles Thomas, Andy Kasper AWS, Charles Tenz, Jacobson, Bill Payne, Walt Johnson, F. Rose, and Don Johnson.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Welding Electrodes

Peoria, Ill.—The regular monthly dinner meeting of the *Central Illinois* Section was held at the Sazarac on November 18th. Extemporaneous talks on the "Manufacture and Inspection of Welding Electrodes" were given by B. W. Knickelbine and O. T. Barnett AWS of the Milwaukee Electrode plant, A. O. Smith Corp. The subject was very well presented. Technical Chairman was E. F. Baker AWS, Superintendent, Structural Steel and Welding, Caterpillar Tractor Co.

Plant Tour

Phoenix, Ariz.—The December meeting of the *Arizona* Section was a plant visitation to the Dye Oxygen Co. of Phoenix, Ariz.

Prior to the evening's program a venison barbecue was served to the members and guests through the courtesy of the Dye Co.

In addition to a very interesting tour of the plant, an unusual film titled "Oxy-Acetylene Flame Master of Metals" was presented.

The Section thoroughly enjoyed the evening and appreciated the many courtesies extended to them by Gil Dye AWS, President, and his staff.

Newly Elected Officers

Phoeniz, Ariz.—The *Arizona* Section announces the election of the following officers:

Chairman—Charles Fogwell, Haywire Welding Works
First Vice-Chairman—J. August Rau, Allison Steel Mfg. Co.
Second Vice-Chairman—William Fischer, 135 Rose Lane
Secretary—Walter Riley, 332 Wilshire Dr.
Treasurer—F. Morris Aspey, Consolidated Western Steel Division, U. S. Steel Corp.
Chairman, Membership Committee—Edward H. Allison, Linde Air Products Co.
Chairman, Program Committee—John D. Dyer, 5706 N. 11th Pl.
Technical Representative—Phillip Binkley, 2229 N. 8th St.

Welded Bridges and Buildings

Pittsburgh, Pa.—The regular monthly dinner meeting of the *Pittsburgh* Section took place on November 18th. Dinner was served to 37 members at the Hotel Webster Hall while 93 were present at the meeting held in the Mellon Institute.

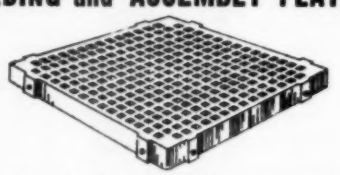
An excellent illustrated discussion on welded bridges and buildings was given by Frederick H. Dill AWS, American Bridge Division, U. S. Steel Corp.

Before the meeting a film entitled "Iron Carbon Alloys" was shown through the courtesy of the American Society for Metals.

Christmas Party

St. Louis, Mo.—On December 11th a Christmas Party was given by the *St. Louis* Section at the Forest Park Hotel

WELDING and ASSEMBLY PLATENS



Floor plates — bending tables — layout tables — straightening tables — dog blocks — bending blocks — blacksmith blocks. 5′x5′ — 6′x6′ — 6′x8′ — 6′x10′ — 5′x10′ — 6′x12′ — 3′x3′ — either 6″ or 7″ thick.

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No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

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Fort Wayne, Ind.

with approximately 45 couples attending. A delicious buffet dinner was served and dancing took place throughout the evening to the delightful music of Herb Mahler's Orchestra. Many old friendships were renewed and a fine spirit of good fellowship prevailed.

Hard Facing

Seattle, Wash.—The *Puget Sound* Section held its December dinner meeting on the 10th at the Engineers' Club in Seattle. A short film on the University of Washington and the University of Utah football game was shown as an after-dinner feature.

Mr. Morry Champers of Automatic Hardfacing, Inc., Everett, Wash., gave an excellent extemporaneous talk on the subject "Hardfacing by the Automatic Process."

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4 sizes for cables #6 through 4/0. Split rubber sleeves for good insulation with friction tape.

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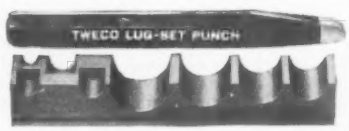
TWECO "LUG-SET"



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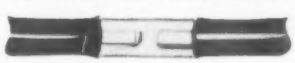

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Nodular Cast Iron

Syracuse, N. Y.—W. M. Boam AWS, Project Engineer for the Wright Aeronautical Corp., Wood Ridge, N. J., was the principal speaker at the December 9th meeting of the *Syracuse* Section. Mr. Boam presented his paper on "Welding of Nodular Cast Iron" which he had previously presented at the National Spring Meeting in Houston and which was published in the September issue of THE WELDING JOURNAL. Additional data covered in Mr. Boam's paper presented at this meeting were along the following lines:

Speaker W. M. Boam

1. It is possible to obtain satisfactory welds on Ni-resist nodular cast iron with a modified Type 430 electrode (known as 431).
2. Best results on ferritic nodular iron were obtained with Ni-rod 55 electrodes.
3. The welds were made without the use of preheat and a stress relieving at 850° after welding was found to be adequate.
4. It was pointed out that small casting defects normally acceptable by radiograph standards had to be repaired prior to assembly welding.
5. It was possible to machine small repaired areas without noticeable difficulties.
6. The welded jet engine assembly using nodular iron joined to stainless steel was produced at $^1/_{16}$ of the original machined design.

Welding Aluminum Alloys

Worcester, Mass.—G. O. Hoglund AWS, Engineer for the Aluminum Company of America, New Kensington, Pa., was the guest speaker at the November

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2nd dinner meeting of the *Worcester* Section held at the Tower House. Mr. Hoglund's illustrated talk on "Welding of Aluminum Alloys" was very well presented and well received by the 57 members present.

Silver Brazing

Worcester, Mass.—Roger J. Metzler AWS of Handy & Harman, New York, was the guest speaker at the December 7th dinner meeting of the *Worcester* Section held at the Tower House with an attendance of 57 at the meeting. Mr. Metzler gave an outstanding talk on the subject "Design for Silver Brazing" which was supplemented by a technicolor sound film entitled "Production Brazing with Low Temperature Alloys."

Spring Meeting
American Welding Society

Statler Hotel—Buffalo, N. Y.

May 4–7, 1954

CURRENT WELDING LITERATURE

Bridges, Steel. Fabrication and Erection Methods for All-Welded Expressway Viaduct, H. H. Tarzian and P. G. Jonas. Roads & Streets, vol. 96, no. 8 (Aug. 1953), pp. 70–77. Shop and field procedures for first leg of extensive system of elevated viaducts in San Francisco described; all members both for piers and superstructure are welded rolled shapes and plates; field welding was done with 300-amp, d-c, arc-welding machines; abstract of specification for structural steel used.

Electric Cables, Joints. Soudage aluminothermique de cables isolés en aluminium, J. Bollinger. Aluminium Suisse, vol. 3, no. 2 (Mar. 1953), pp. 62–65. "Alutherm" welding of underground and insulated aluminum cables described; molten metal employed; melting of weld metal and ends of conductors to be joined occurs simultaneously; conductivity of cable not impaired; simplicity of method stressed. (In French and German.)

Electric Machinery, Windings. Enamelled Round Copper Wire. Brit. Standards Instn.—Brit. Standard, no. 1961 (1953). 23 pp. Standard is intended to cover only requirements of oil base enameled wire used for winding coils for electrical machinery and apparatus; all sizes of wire from 0.025 to 4 mm diam, commonly in use, are included; limited number only of sizes having thick covering are included.

Fire Protection. Welding Torch Fires, H. E. Beaven. Factory Mgmt. & Maintenance, vol. 111, no. 7 (July 1953), pp. 132–133. Causes of torch fires; notes on general preventive measures and measures applying specifically to oxy-acetylene and electric welding equipment and gasoline blow torches; tabulation of eight typical torch fire losses.

Machinery Exhibitions, London, England. What to See at Olympia, Shipbldg. & Shipg. Rec., vol. 8, no. 8 (Aug. 20, 1953), pp. 249–253; no. 9 (Aug. 27), pp. 287–289; no. 10 (Sept. 3), pp. 317–319; no. 11 (Sept. 10), pp. 347–349; no. 12 (Sept. 17), p. 387; see also Gas & Oil Power, vol. 48, no. 577 (Aug. 1953), pp. 184–191; Machy. Market, no. 2755 (Sept. 4, 1953), pp. 29–36; no. 2756 (Sept. 11), pp. 33–44; no. 2757 (Sept. 18), pp. 28–29; Mar. Engr. & Naval Architect, vol. 76, no. 920 (Sept. 1953), pp. 354–361; Brit. Motor Ship, vol. 34, no. 403 (Oct. 1953), pp. 300–303. Illustrated description of exhibits at 19th biennial Engineering, Marine and Welding Exhibition and Chemical Plant Exhibition held at Olympia, London, Sept. 3–17, 1953.

Metals Testing. Ultrasonics in Testing of Metal Plates and Welds. Petroleum Times, vol. 57, no. 1464 (Sept. 18, 1953), pp. 935–936. Ultrasonic inspection apparatus applied by Monk Bretton Works, near Barnsley, Great Britain, for detection of rolled slag inclusions in steel plates used for construction of fractionating column; principle of work with echo pulse reflection apparatus.

Power Supplies and Resistance Welders, A. B. White. Industry & Power, vol. 64, no. 4 (Apr. 1953), pp. 86–89, 100. In earlier resistance welding equipment kva demand of machines was high and distribution systems were inadequate; how recent improvements have overcome these difficulties; development of distribution equipment which makes load center distribution system practical; developments in welders; current trend toward 3-phase welders.

Television Receivers, Manufacture. Soldering 1000 Leads in One Mechanized Operation, K. M. Lord. Factory Mgmt. & Maintenance, vol. 111, no. 7 (July 1953), pp. 108–109. Factors involved in conversion to mechanized soldering for television assembly at General Electric's Electronic Park, Syracuse, N. Y.; dip solder machine consists of flux tank, solder tank, sprocket-driven endless chain conveyor and auxiliary equipment; capacity is 350 chassis units per hour.

Water Pipe Lines. Portland, Ore., Builds New Pipe Line, G. B. Arthur. Pub. Works, vol. 84, no. 8 (Aug. 1953), pp. 80–81, 142–144. Portland builds 10 miles of 66-in. and 15½ miles of 56-in. welded steel water pipe lines; illustrated description of laying, welding, testing, and corrosion protection.

LIST OF NEW MEMBERS

Effective November 30, 1953

MEMBERSHIP CLASSIFICATION

A—Substaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ANTHONY WAYNE

Raab, Joe W. (B)

BIRMINGHAM

Adderhold, C. H. (C)
George, Earl A. (C)
Pfeiffer, Harry (B)
Wilson, Otis L. (B)

BOSTON

Reed, Albro P. (C)
Rimmler, Carl H. (B)
Schleiff, Carl G. (C)
Taylor, Winthrop P. (C)

CHICAGO

Eberhardt, Andrew (B)
Steinmetz, John J. (B)

CINCINNATI

Spargur, Charles R. (B)
Young, William H. (B)

CLEVELAND

Ghinder, John V. (C)
Hoff, William Robert (C)
King, David (C)
Perry, W. Lyle (C)
Tupper, Arthur S., Jr. (C)
Walter, C. N. (B)

COLORADO

Garver, W. L. (C)

COLUMBUS

Carey, Donald P. (C)
Long, Terry (C)
Warrender, Ralph (C)

DALLAS

Hart, Arthur J. (C)
Maner, D. C. (C)

DAYTON

Carroll, F. E., Jr. (C)
Curtis, Wilson E. (C)
Phillis, Cars D. (C)
Scott, Gerald E. (C)

DETROIT

Christy, C. E. (C)
Davenport, Murl W. (B)
Dingell, Ed (B)
Driver, Harry Leon (C)
Edwards, Robert L. (B)
Gleason, Quin (C)
Hean, Harry W. (C)
Karasienski, John A. (C)
McClain, Raymond E. (B)
Reed, James M. (B)
Weadley, Wm. Stanley (B)

HOUSTON

Allen, Ben H., Jr. (D)
Bradbury, Walter A. (B)
Brown, Rodgers P., Jr. (C)
Christian, Ray (C)
Clare, R. T., Jr. (B)
Edquist, Sanford F. (C)
Fanestiel, Albert (B)
French, Paul R. (B)
Gober, Forrest (B)
Hamilton, W. B., Jr. (B)
Harrell, Dan (B)
Hollingsworth, C. E., (B)
Hutzler, John E. (C)
McCoskey, Clarence R. (D)
McFaull, Steve (C)
Miner, Vernon L. (B)
Naschke, John H. (B)
Potter, Tom (C)
Powell, W. E. (C)
Sietta, Sam S. (B)
Sims, Wayne K. (C)
Streng, Walter G. (D)
Ulrich, Ray Fred (D)
Voskamp, Earl L. (B)
Wells, Carl C. (B)
Williams, Tommie (B)

INDIANA

Hanson, Peter G. (B)
Leeper, Paul W. (C)

IOWA-ILLINOIS

Smith, Howard F. (C)
Wrage, Elmer Wm. (C)

LEHIGH VALLEY

Jones, Emerson W., Sr. (B)
Kleppinger, Walter W. (C)

LOS ANGELES

Dever, Frederick S. (B)
Fowble, James Raymond, Jr. (B)
Nearhoff, Rodger Clark (C)
Terry, Richard (C)

MAHONING VALLEY

Robson, Leonard K. (C)
Shay, Eli (B)
Walkosak, Robert M. (D)

MICHIANA

Hunt, Fonzo C. (C)
Spencer, Lyle J. (C)

NEW JERSEY

Frail, Earl H. (C)
Greiff, J. Fred (B)
Huber, Alfred L. (B)
Leith, Martin Louis (B)
Pabst, Walter W. (B)

NEW YORK

Bregman, David (B)
Collins, John (B)
Shaw, F. (B)

NIAGARA FRONTIER

Karoczun, Alex(C)
Korzenski, Ralph (B)

NORTHERN NEW YORK

Valachovic, Anthony J. (C)
Wagman, Walter (B)

NORTHWEST

Fletcher, Norman Ferris (C)
Thomas, Russell (C)

NORTHWESTERN PENNSYLVANIA

Mooney, Thomas E. (C)

PEORIA

Fader, Donald (C)
Goodrich, Russell R. (C)
Slover, Garold (C)

PHILADELPHIA

Downey, Edwin L. (B)
Olsen, WilliamW. (B)
Rosica, Herman J. (B)
Salt, Harry E. (B)
Schultz, Frank J. (B)
Wisniewski, Walter S. (B)
Zaslow, Edward (B)

PITTSBURGH

Reagan, Edward J. (B)
Steppling, Raymond (B)
Tierney, George A. (B)
Wright, A. R. (C)
Zegarsky, Lewis H. (B)

PORTLAND

Evanson, Arthur H. (C)
Owen, Lewis (B)

PUGET SOUND

Holumstrom, Robert A. (B)
Humphries, Tom C. (B)
La Rock, Clifford E. (B)
Van Sickle, William F. (C)

RICHMOND

Bennedetti, G. W. (C)

ROCHESTER

O'Brien, Frederick Edward (C)

SAGINAW VALLEY

Blumenstein, Robert M. (C)
Divers, C. Kenneth (D)
Greenough, John Gerald (D)
Henry, Bill (B)
Mack, Floyd C. (B)
Regelbrugge, Roger R. (D)
Snodgrass, John N. (D)
Wuepper, Clarence L. (C)

SALT LAKE CITY

Bergstrom, Elwyn L. (C)
Osborne, Earl, Jr. (B)

SAN FRANCISCO

Bionaz, Emery L. (C)
Christopherson, Don L. (B)
Yeoman, Arthur E. (C)

SYRACUSE

Bareham, George A. (C)
Connolly, Clarence M. (C)
Cook, Harry W. (C)
Downey, Charles (C)
Hahn, Alfred (C)
Wise, William L. (C)

TOLEDO

Dray, Edward W. (B)

TUCSON

Brennan, Joseph H. (C)

TULSA

Bonham, Dan S. (B)
Cooper, Virgel E. (B)
Putsche, Charles H. (B)
Ryan, Art (B)
Schuette, J. E. (C)
Travis, Marshall (B)
Wright, William R., Jr. (B)

WESTERN MASSACHUSETTS

Cote, Norman E. (B)
Staples, Frank A., Jr. (C)
Thomson, Edwin W. (B)

WESTERN MICHIGAN

Brock, Gilbert H. (B)
Grafford, John G. (B)
Reinke, Nelson A., Sr. (B)

WORCESTER

Frye, William H. (B)

YORK-CENTRAL PENNSYLVANIA

Edelson, Albert (B)
Flynn, Christopher A. (C)

NOT IN SECTIONS

Allen, Lloyd E. (C)
Cates, Robert L. (B)
Donaldson, Hubert J. (C)
Herauf, Douglas (B)
Swire, Walter (B)

Members Reclassified

During the month of December

BOSTON

Siraco, Peter (C to B)

CHICAGO

Bailey, E. C. (C to B)

DETROIT

Kaunitz, C. F. (C to B)

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150	238	325	450	800	1150	1500	1850
163	250	338	500	850	1200	1550	1900
175	263	350	550	900	1250	1600	1950
188	275	363	600	950	1300	1650	2000

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Supplement to the Welding Journal, February 1954

Destruction Tests and Design Data for Welded Pressure Vessels

Results of tests on Alcoa's aluminum alloy A54S (ASTM GR40A) to develop welding procedures and design data for fabrication of pressure vessels

by John B. Custer

THE competitive position of aluminum alloys in the construction of unfired pressure vessels and welded structures has been improved with the announcement of a high-strength, nonheat-treatable commercial alloy designated A54S by Aluminum Company of America and GR40A by the American Society for Testing Materials.

A growing demand for aluminum alloys in tanks, processing equipment, and welded structures has made the aluminum industry aware of the need for higher-strength alloys. The development of A54S aluminum alloy has provided an answer to this need for higher strength. This, in conjunction with its high resistance to corrosion by various waters, chemicals and foods; its lightweight, nonsparking properties, high thermal conductivity and adaptability to being easily formed and welded provides an aluminum alloy that is better suited to meet the fabricators' requirements for welded construction.

The merits of A54S alloy were established by a test program carried out by the Aluminum Company of America. This program included: (1) The development of the most desirable welding methods along with welded-joint strength data; (2) the construction, based on the welding-development results, of four tanks representative of typical shop quality; and (3) the destructive hydrostatic testing of these tanks to provide proof of the strength characteristics of this new alloy.

The results of the welding-development program, part of which are shown in Fig. 1, were used to choose fabrication procedures for the test tanks. These procedures, details of which are outlined in Fig. 2, were felt to be the optimum for production of the strongest vessels. The welding terminology used in the data and throughout the text are defined as follows:

1. *Tungsten arc:* Argon-shielded, tungsten electrode, a-c current, manual manipulation.
2. *Consumable electrode:* Argon-shielded, aluminum alloy electrode, d-c current, semiautomatic operation with machine-fed electrode.

The strengths of welds made by the two methods are approximately the same. They have, therefore, been grouped together in Fig. 1 showing the strengths of welds in sheet and plate from $^1/_8$- to 3-in. thick. The tungsten arc method of welding consumes more time and thus produces greater heat distortion of the parts being welded. The consumable electrode provides a greater concentration of heat with a resulting faster weld rate and less distortion. Because of this high concentration of heat and a faster rate of filler metal deposition, penetration is more easily effected and weld cracking is minimized.

The four test tanks were made of $^1/_8$-, $^1/_4$-, $^1/_2$- and 1-in. thick sidewalls with a length-to-diameter ratio of

John B. Custer is with the Alcoa Process Development Laboratories, Aluminum Company of America, New Kensington, Pa.

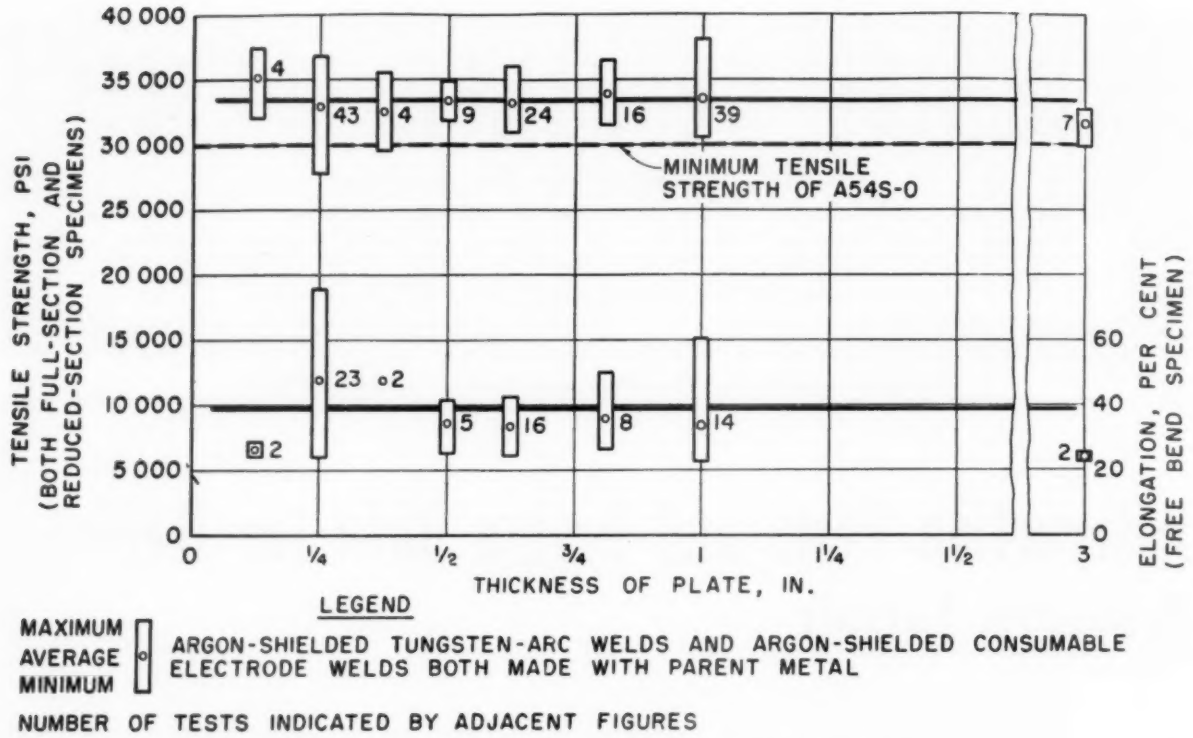
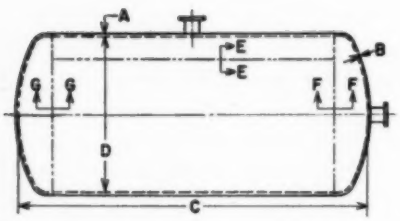


Fig. 1 Strength and ductility of butt (groove) welds in A54S plate



DIMENSIONS AND TEST RESULTS							
TANK	A IN.	B IN.	C IN.	D IN.	BURST PRESSURE, P.S.I.	CALCULATED HOOP STRESS, P.S.I.	FAILURE LOCATION
1	1/8	1/8	44 1/8	15 5/8	600	37,800	LONGITUDINALLY, ADJACENT TO WELD.
2	1/4	1/4	70	27	700	38,200	LONGITUDINALLY, ADJACENT TO WELD.
3	1/2	1/2	70 1/2	27	1,185	32,700	LONGITUDINALLY, THROUGH WELD.
4	1	25/32	106 1/4	40 1/2	1,505	31,400	LONGITUDINALLY, ADJACENT TO SIDEWALL FITTING REINFORCING PAD.

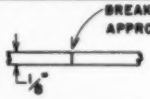
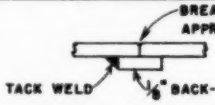
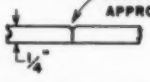
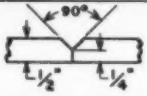
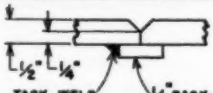
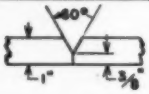
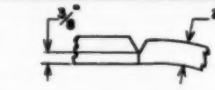
CONSTRUCTION DETAILS, A54S ALUMINUM ALLOY TEST VESSELS				
TANK	SECTION E-E EDGE PREPARATION	SECTION F-F EDGE PREPARATION	SECTION G-G EDGE PREPARATION	REMARKS
1	BREAK EDGES APPROX. 1/32"  TUNGSTEN ARC WELD	BREAK EDGES APPROX. 1/32"  TACK WELD 1/8" BACK-UP STRIP TUGSTEN ARC WELD	SAME AS SECTION F-F	1. ALL JOINTS RADIOGRAPHED. 2. A54S WELD FILLER WIRE USED THROUGHOUT.
2	BREAK EDGES APPROX. 1/16"  CONSUMABLE ELECTRODE WELD	BREAK EDGES APPROX. 1/16" TACK WELD 3/16" BACK-UP STRIP CONSUMABLE ELECTRODE WELD	SAME AS SECTION F-F	1. ALL JOINTS RADIOGRAPHED. 2. A54S WELD FILLER WIRE USED THROUGHOUT. 3. FITTINGS PROVIDED WITH REINFORCING PADS.
3	90° 1/2" 1/4"  CONSUMABLE ELECTRODE WELD	1/2" 1/4"  TACK WELD 1/4" BACK-UP STRIP CONSUMABLE ELECTRODE WELD	SAME AS SECTION F-F	1. ALL JOINTS RADIOGRAPHED. 2. A54S WELD FILLER WIRE USED THROUGHOUT. 3. FITTINGS PROVIDED WITH REINFORCING PADS.
4	60° 1" 3/8"  CONSUMABLE ELECTRODE WELD	3/8" 25/32"  CONSUMABLE ELECTRODE WELD	1/2" BACK-UP STRIP TACK WELD CONSUMABLE ELECTRODE WELD	1. ALL JOINTS RADIOGRAPHED. 2. A54S WELD FILLER WIRE USED THROUGHOUT. 3. FITTINGS PROVIDED WITH REINFORCING PADS.

Fig. 2 Construction details, A54S aluminum alloy test vessels

Table 1—Results of Tensile Tests of Original Plate and of Specimens Taken from A54S Aluminum-Alloy Fusion-Welded Pressure Vessels

Vessel	*Thickness, in.*	*Source of specimen*	*Tensile strength, psi*	*Yield strength,* psi*	*Elongation in 2 in. or 4D,%*
1	1/8	Original plate	48,900	46,400	5.5
		180 deg from weld	45,300	36,700	11.0
		Across weld	38,400	30,600	9.0
2	1/4	Original plate	45,700	42,100	8.5
		10 in. from weld	44,100	38,400	12.0
		Across weld	32,200	24,500	12.0
3	1/2	Original plate	33,300	12,300	32.3
		16 in. from weld	36,600	26,200	21.6
		Across weld	32,400	22,600	12.8
		All weld	32,900	22,800	10.6
4	1	Original plate	34,000	16,100	31.5
		12 in. from weld	36,200	24,800	23.0
		Across weld	34,000	24,600	13.0
		All weld	33,200	22,400	18.5

* Offset equals 0.2%.

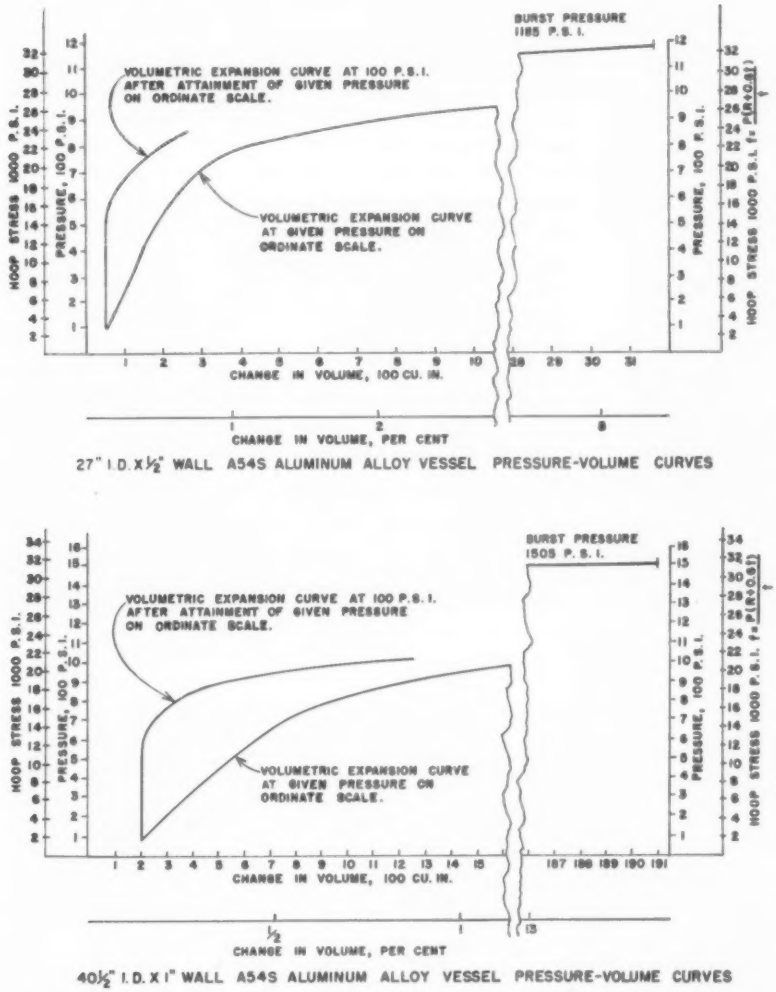

BURST PRESSURE
1185 P.S.I.
VOLUMETRIC EXPANSION CURVE AT 100 P.S.I. AFTER ATTAINMENT OF GIVEN PRESSURE ON ORDINATE SCALE.
VOLUMETRIC EXPANSION CURVE AT GIVEN PRESSURE ON ORDINATE SCALE.
HOOP STRESS 1000 P.S.I.
PRESSURE, 100 P.S.I.
CHANGE IN VOLUME, 100 CU. IN.
CHANGE IN VOLUME, PER CENT
27" I.D. X 1/2" WALL A54S ALUMINUM ALLOY VESSEL PRESSURE-VOLUME CURVES
BURST PRESSURE
1505 P.S.I.
VOLUMETRIC EXPANSION CURVE AT 100 P.S.I. AFTER ATTAINMENT OF GIVEN PRESSURE ON ORDINATE SCALE.
VOLUMETRIC EXPANSION CURVE AT GIVEN PRESSURE ON ORDINATE SCALE.
HOOP STRESS 1000 P.S.I.
PRESSURE, 100 P.S.I.
CHANGE IN VOLUME, 100 CU. IN.
CHANGE IN VOLUME, PER CENT
40 1/2" I.D. X 1" WALL A54S ALUMINUM ALLOY VESSEL PRESSURE-VOLUME CURVES

Fig 3 1/2 in. and 1 in. wall A54S aluminum alloy Pressure-Volumetric expansion curves

2:1. Spun semiellipsoidal heads with major-to-minor axes ratio of 2 : 1 were employed. All the welding on the 1/8-in. wall vessel was done by the tungsten arc process; whereas that of the other vessels was done by the consumable electrode method. Alloy A54S filler wire was used throughout. Complete design details of each individual vessel are shown in Fig. 2.

The testing portion of the program consisted of slowly increasing the hydrostatic pressure in each vessel until failure occurred. Volumetric expansions were noted after increments of pressure for both the 1/2- and 1-in. wall vessels in order to illustrate the yield characteristics of the alloy. Total circumferential growth at failure was also recorded for these vessels to determine approximately the elongation characteristics under biaxial stress conditions.

The pressures at failure and the computed hoop stresses are given in Fig. 2 and the volumetric expansion data are plotted in Fig. 3. The circumference of the 1/2-in. wall vessel increased 6.3% while that of the 1-in. wall vessel increased 9.9%.

After testing, the structures of some of the welds were examined by polishing and etching cross sections of intact portions of the longitudinal seams of the 1/2- and 1-in. wall vessels. These sections are shown in Fig. 4.

Coupons for tensile tests were removed from each vessel so as to obtain strength data across the weld and in the shell sections away from the heat-affected zone. In tests of specimens taken across the weld, it should be remembered that values for both elongation and yield strength are dependent upon the gage length. In these specimens, the weld surfaces were within the gage length and were not machined. Therefore, the specimens were not uniform either in cross section or structure, and the mechanical properties would be expected to vary considerably from the flat plate specimens.

Results of these tests are shown in Table 1, along with the results of mill tests made at the time the metal was rolled. In the two thickest vessels, the higher tensile strengths and yield strengths of the plate 12 to 16 in. from the weld, as compared with the original prop-

Table 2—Typical Tensile Properties of A54S Sheet—Thickness Not Greater Than 0.250 In.

Temper	Tensile strength, psi	Yield strength,* psi	Elongation in 2 in., %
A54S-O	35,000	15,000	25
-H32	39,000	30,000	14
-H34	42,000	33,000	12
-H36	45,000	36,000	9
-H38	48,000	39,000	8

* Offset equals 0.2%.

erties of the plate, are the results of cold working of the plate during construction and testing of the vessels. By comparison with the typical properties given in Table 2, it will be seen that the 1/8- and 1/4-in. materials have properties about equivalent to those of the -H38 temper.

It may be seen from Fig. 2 that the calculated hoop stress at time of failure ranged from 31,400 psi for the 1-in. wall vessel to 38,200 psi for the 1/4-in. wall vessel.

Table 3—Typical Tensile Properties of A54S-O Plate

Thickness, in.	Tensile strength, psi	Yield strength,* psi	Elongation in 2 in., %
0.250	34,000	15,000	28
0.375	34,000	14,000	29
0.500	34,000	13,000	29
1.000	34,000	13,000	29

* Offset equals 0.2%.

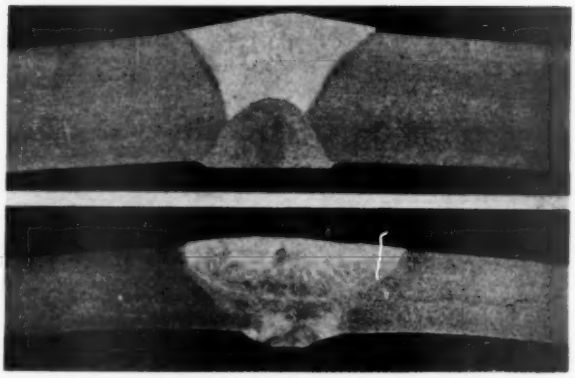


Fig. 4 (Above) 1-in. thick A54S aluminum alloy vessel longitudinal weld section. (Below) 1/2-in. thick A54S aluminum alloy vessel longitudinal weld section

As can be seen in Figs. 5, 6 and 7, the failures in the 1/8-, 1/4- and 1/2-inch wall vessels were either in or adjacent to the longitudinal weld. This is as might be expected because this region of the plate is partially annealed by the heat of welding. The fracture of the 1-in. wall vessel as shown in Fig. 8 was nearly tangent to the reinforcing pad around a nozzle opening in the shell. Although this may seem unusual, it is recognized that this type of construction introduces a nonuniform stress condition. The computed average hoop stress in this case was 31,400 psi.

The volumetric expansion of the 1/2- and 1-in. wall vessels, shown graphically in Fig. 3, portrays the yield

Table 4—Typical Tensile Properties of A54S Products at Various Temperatures

Temp., ° F.	Tensile strength, psi, after holding at testing temperature: 1/2 hr	10,000 hr	Yield strength,* psi, after holding at testing temperature: 1/2 hr	10,000 hr	Elongation in 2 in., % after holding at testing temperature 1/2 hr	10,000 hr
A54S-O						
-320	51,000	...	17,000	...	40	...
-112	36,000	...	15,000	...	32	...
0	35,000	...	15,000	...	28	...
75	35,000	35,000	15,000	15,000	25	25
212	35,000	35,000	15,000	15,000	30	30
300	30,000	30,000	15,000	15,000	40	40
400	23,000	23,000	13,000	13,000	45	45
500	16,000	16,000	8,000	8,000	65	65
600	9,500	9,500	5,000	5,000	90	90
700	5,000	5,000	3,000	3,000	120	120
A54S-H34						
-320	57,000	...	39,000	...	24	...
-112	44,000	...	34,000	...	17	...
0	42,000	...	33,000	...	14	...
75	42,000	42,000	33,000	33,000	12	12
212	40,000	40,000	32,000	31,000	15	15
300	35,000	34,000	30,000	28,000	23	25
400	26,000	26,000	18,000	18,000	30	30
500	16,000	16,000	8,000	8,000	65	65
600	9,500	9,500	5,000	5,000	90	90
700	5,000	5,000	3,000	3,000	120	120
A54S-H38						
-320	64,000	...	46,000	...	20	...
-112	50,000	...	40,000	...	15	...
0	49,000	...	39,000	...	12	...
75	48,000	48,000	39,000	39,000	8	8
212	46,000	45,000	38,000	37,000	12	14
300	41,000	39,000	33,000	30,000	18	20
400	30,000	29,000	18,000	18,000	35	35
500	16,000	16,000	8,000	8,000	65	65
600	9,500	9,500	5,000	5,000	90	90
700	5,000	5,000	3,000	3,000	120	120

* Offset equals 0.2%

characteristics of the alloy. The curves of the 1/2-in. wall vessel indicate the beginning of permanent set to be at approximately 500 psi pressure or a computed hoop stress* of 13,800 psi. The pressure at first permanent set of the 1-in. wall vessel was approximately 650 psi pressure which corresponds to a computed hoop stress of 14,000 psi. These figures agree with the typical yield strength of annealed plate as given in Table 3. Typical tensile properties for sheet are shown in Table 2 and typical properties at various temperatures are shown in Table 4.

It can be concluded from these test results and laboratory data that A54S aluminum alloy can be advantageously employed in the design of pressure vessels. The results of the destruction tests indicate that the strength of welded joints is at least equal to the specified minimum tensile strength of unwelded annealed plate. Therefore, the design values shown in Table 6 (based on Table 5) for the annealed temper at room temperature are justified.

Experience gained during construction and testing of these vessels, as well as during other investigational work, has indicated that the formability of this alloy

Fig. 5 1/2 in. wall A54S aluminum alloy pressure vessel tested to destruction

Fig. 6 1/4 in. wall A54S Aluminum alloy pressure vessel tested to destruction

Fig. 7 1/2 in. wall A 54S aluminum alloy pressure vessel tested to destruction

* $f = P(R + 0.6t)/t$. Where f = stress, psi; P = pressure, psi; R = inside radius, in.; and t = shell thickness, in.

Fig. 8 1 in. wall A54S aluminum alloy pressure vessel tested to destruction

Table 5—Minimum Tensile Properties of A54S Plate in Thickness Range 0.250–2.000 In.

Temper	*Tensile strength, psi*	*Yield strength,* psi*	*Elongation in 2 in., %*
A54S-O	30,000	11,000	18
-H32	36,000	26,000	8
-H34	39,000	29,000	6
-H36	42,000	32,000	5
-H112	30,000	11,000	8

* Offset equals 0.2%.

Table 6—Suggested Pressure Vessel Design Stresses for Temperatures Up to 400° F, Aluminum Alloy A54S, 4:1 Safety Factor*

Temper	*Design stress, psi, for metal temperature not exceeding:* 100° F	150° F	200° F	250° F	300° F	350° F	400° F
A54S-O†	7350	7350	7350	7000	6400	5650	4900
A54S-H112	7350	7350	7350	7000	6400	5650	4900
A54S-H32	9000	8950	8850	8250	7400	6550	5600
A54S-H34	9750	9700	9500	8800	7900	6900	5900

* These data are based on one-quarter tensile strength or two-thirds yield strength, whichever is less.
† For welded construction, stress values for 0 material shall be used.

is comparable to that of 52S* aluminum alloy. Except in certain cases involving critical forming operations, A54S can be formed on equipment developed for 52S and 61S† alloys.

The use of the higher design stresses permissible with this new alloy can result in thinner sections, thereby enhancing the competitive position of aluminum by reducing cost and weight. Designers are finding the alloy attractive not only for the construction of stationary process equipment such as piping, vessels and tanks, but also for mobile units where light weight is important. Already some companies are experimenting with A54S aluminum alloy in applications such as dry bulk haulage trailers, tank cars and tank trailers. One company is at present manufacturing earth movers of 61-cu yd capacity.

The excellent welding and forming characteristics and high strength of welded joints in conjunction with the natural advantages of aluminum—light weight, corrosion resistance, nonsparking properties and high thermal conductivity—made aluminum alloy A54S truly a metal with a bright and promising future.

Postscript: Since the writing of this article, aluminum alloy A54S (ASTM Designation GR 40A) has been approved for use in the construction of unfired pressure vessels fabricated by fusion welding under the applicable rules of section VIII, 1952 ASME Unfired Pressure Vessels Code. See publication of special ruling, Case 1174, December 1953 Issue of Mechanical Engineering.

* Alloy GR20A of ASTM Spec. B-178–52T.
† Alloy G81lA of ASTM Spec. B-178–52T.

Pressure Vessel Research in the Universities

by Perry R. Cassidy

THE Pressure Vessel Research Committee is utilizing University Research facilities exclusively for its sponsored research. The resulting research has been very satisfactory at Purdue with Dr. Sturm, at Lehigh—first with Bruce Johnston and then with Robert Stout, at the University of Illinois with Thomas Dolan and Professor Bowman, at École Polytechnique with Dr. Welter, and at Cornell with Professor Winter and Professor Bijlaard.

All of our research projects have been correlated to a common objective. With our limited budget we have concluded that we cannot afford to diffuse our research to unconnected projects. We decided to concentrate upon a single objective: a study of high-tensile steels for pressure vessels and the effect of concentrated stresses in vessels made from such steels with average design stresses in the shell at $^5/_8$ to $^3/_4$ yield stress. There is no design experience of any extent or for any length of time to guide us in this research. Most experience in pressure vessels has been with carbon steel such as A201, A285 and A212 at average design stresses of one-fourth minimum ultimate specified.

In order to simplify the problem, we have considered only the most favorable conditions of design and operation. These are:

1. Materials—only flange or firebox.
2. Stress concentration reduced by reduction in discontinuities.
3. Full penetration butt welds, X-rayed and machined flush.
4. Stress relieved after welding.
5. Noncorrosive operating conditions.

It is recognized that these conditions would apply only to maximum pressure and a favorable class of vessels. The ordinary class of run-of-mine vessels would not be included.

Without corrosion or any condition which would result in thinning of the walls of the vessel, it is assumed that an average design stress which would permit a hydrostatic test of $1^1/_4$ design pressure would not distort the vessel even with a design stress of $^3/_4$ yield strength. The stress at hydrostatic pressure would be $^{15}/_{16}$ yield strength. At points of stress concentration the stress would exceed yield stress under hydrostatic pressure resulting in plastic yield, a residual compression, but a range in stress and strain unchanged.

Our research projects are all directed to determining the effect of such concentrated stresses and strains in

(*Continued on page 78-s*)

Perry R. Cassidy is Chairman, Pressure Vessel Research Committee of the Welding Research Council.

Summary of remarks made at University Research Conference, Cleveland, Oct. 21, 1953.

Effects of Peening Last Pass of Welds

Peening last pass is undesirable if weldment is expected to serve at low winter temperatures

by W. S. Pellini and E. W. Eschbacher

Abstract

Explosion Bulge tests were conducted to determine the effects of peening the last pass of E6010 VV butt welds of ABS-B ship plate. The performance of the weldments is shown to be severely impaired by peening due to embrittlement of the weld metal. It is concluded that peening of the last pass is a hazardous practice if the weldment is expected to serve at temperatures such that the base steel is susceptible to the initiation and propagation of brittle fractures.

INTRODUCTION

PEENING of welds to control distortion is essential to the solution of many fabrication problems. The various codes which govern welding procedures permit such peening with the exception of the last pass. The restriction is based on the general opinion of the various code authorities that the cold work associated with peening is detrimental to weld ductility. In the case of the intermediate passes the damage is considered to be eliminated by the heating effects of the subsequent pass and accordingly is permitted.

While the restriction to peening the last pass has been in effect for many years there has been considerable contention by fabricators, desirous of using peening for the last pass, that the regulation is both unnecessary and arbitrarily restrictive. This contention is based on the fact that data showing positive damage to the performance of weldments due to peening of the last pass were not available. Thus, the subject and problem of peening last passes has remained a controversial one.

In order to resolve this question the Welding Research Council, through the Peening Committee, sponsored an extensive investigation concerned with the evaluation of the notch ductility of as-deposited and peened weld metal. The results of this investigation, which was conducted at the American Bureau of Shipping Laboratory, have been made available in a previous report.[1] Briefly, it was demonstrated by modified Charpy tests that the effects of peening were detrimental to weld notch ductility.

The development of the Explosion Bulge Test for the evaluation of full-size weldments provided a means for direct comparison of the performance of peened and as-deposited weldments. Inasmuch as the problem of peening last passes is of interest to the Navy the tests were conducted at the Naval Research Laboratory in cooperation with the research program of the Welding Research Council. The American Bureau of Shipping provided the weldments.

MATERIALS AND PROCEDURES

The weldments used in this investigation were prepared from 1-in. thick ABS-B ship plate (0.18% C, 0.75% Mn, 0.03% Si, 0.033% S, 0.013% P). Two 12- x 24-in. plates were joined by a 60-deg VV butt weld to form a 24- x 24-in. weldment. The weldments were prepared by a commercial fabricator under the direction of the American Bureau of Shipping. The welding conditions were as follows: E6010 electrode, $^5/_{32}$-in. diam, d-c reverse polarity, 45-deg position. The first pass was chipped to ensure soundness; all welds were radiographed and any defects noted were repaired. The welding was performed under average shop conditions and is considered representative of production quality. A total of 23 weldments were prepared of which 12 were selected for peening.

Peening was performed by the American Bureau of Shipping using an automatic machine which provided close control and reproducibility of the peening conditions. The following conditions were used: heavy hammer, tool with $^1/_4$-in. diam nose, 90 psi air pressure, 25-lb riding load, $3^3/_8$ ipm travel speed, frequency of blows 1400/ min, energy output 14 ft-lb per blow. These conditions were considered to represent "heavy" peening and mild flaking was observed to develop during the operation.

All weldments were flame cut to the 20- x 20-in. size required for the Explosion Bulge Tests by removing 2-in. wide strips from each of the four sides. The strips were saw cut to remove material affected by the flame-cutting operation and the cut sections were polish-

W. S. Pellini and **E. W. Eschbacher** are with the Naval Research Laboratory, Washington, D. C.

Presented at the AWS Thirty-Fourth National Fall Meeting held in Cleveland, Ohio, week of Oct. 19-23, 1953.

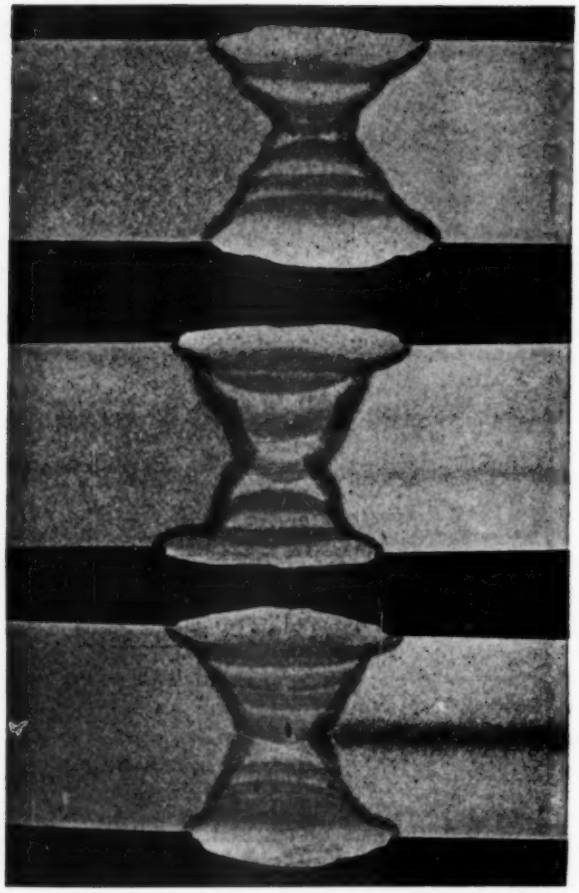


Fig. 1 Representative macrographs of welds

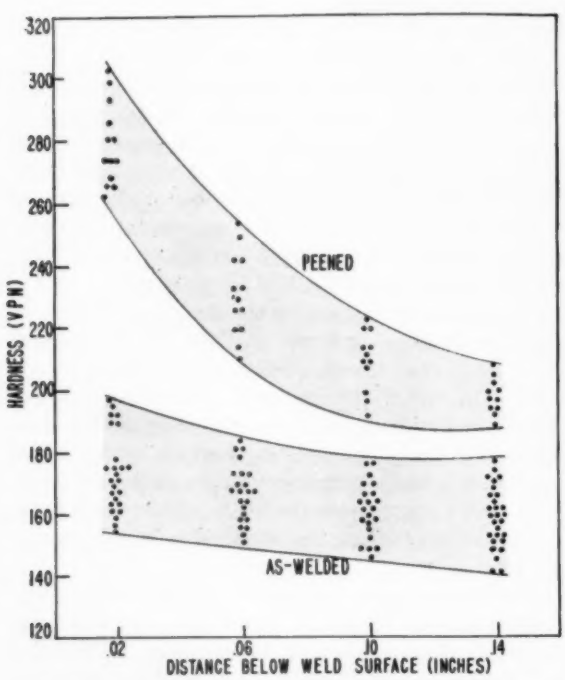


Fig. 2 Summary of Vickers hardness tests of weld metal

ground and etched to examine the weld contour; Fig. 1 shows representative macrographs. Vickers hardness determinations were made over a distance from 0.02 to 0.14 in. below the weld surface for each sample. Figure 2 summarizes the results of the hardness tests for the as-welded and peened samples. It is observed that the peening operation increased the hardness of the welds approximately 100 VPN near the surface and approximately 30 VPN at the 0.14-in. position. This phase of the investigation was conducted at the Laboratory of the American Bureau of Shipping.

EXPLOSION BULGE TESTS

The explosion tests were made according to the standard practice developed for weldment evaluation. The weldments were cooled or heated to desired test temperatures, placed over a circular die and loaded by the detonation of a 4-lb Pentolite charge positioned 15 in. above the plate. Figure 3 illustrates the method. The high energy gas pressure developed by the explosion clamps the plate rigidly to the die and causes bulg-

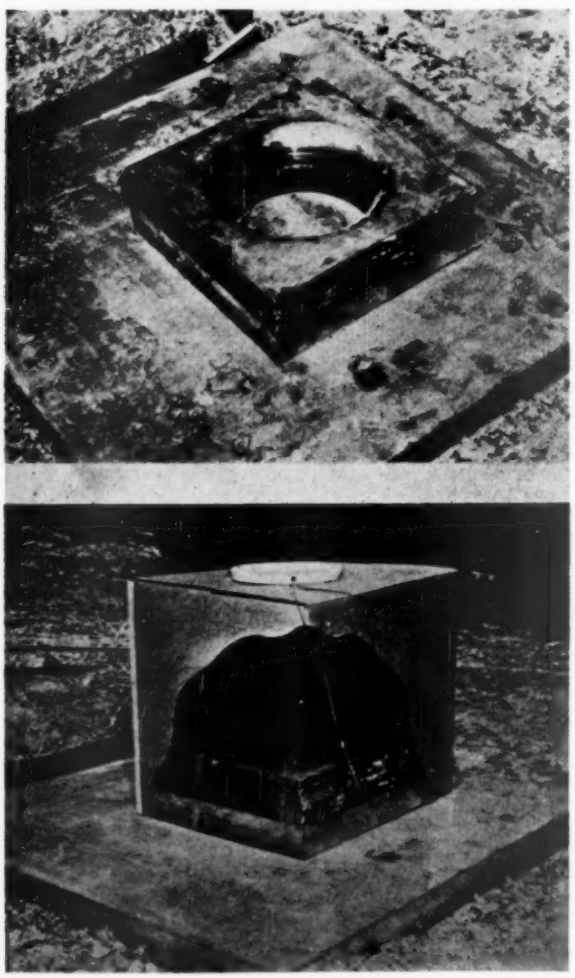


Fig. 3 Explosion Bulge Test. Circular die (top) and a test weldment in position for firing (bottom). The explosive wafer (standard 4 lb charge) is placed on top of a cardboard box used to establish the desired 15-in. offset distance

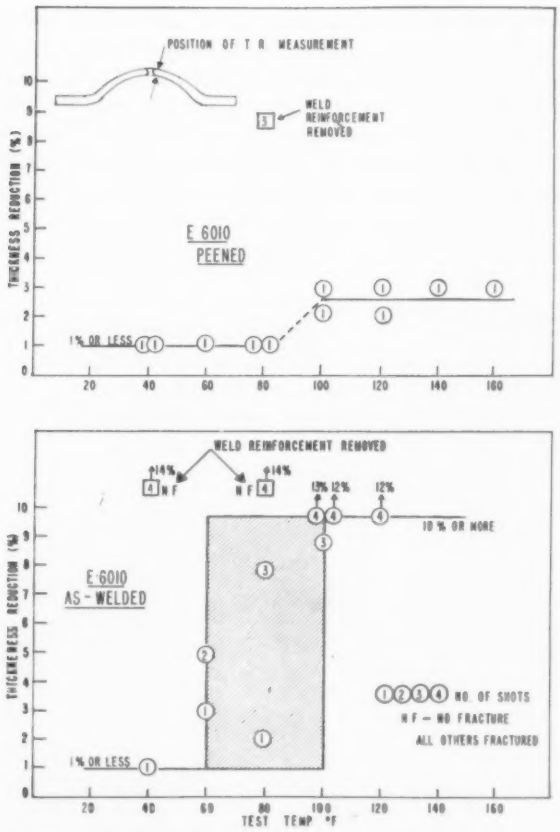


Fig. 4 Explosion Bulge performance of weldments at various temperatures; thickness reduction at failure and number of shots required for failure

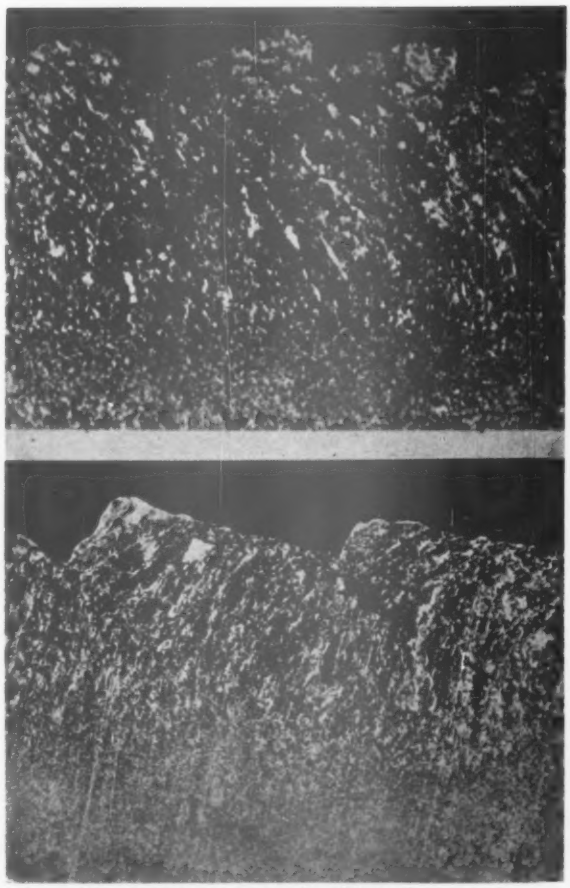


Fig. 6 Cross section of weld ripples. × 10

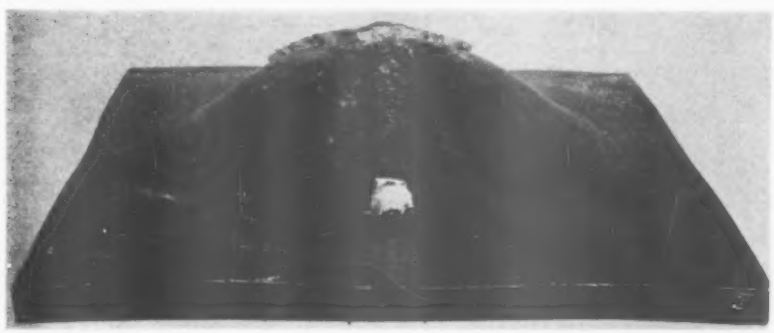


Fig. 5 Bulge deformation at 4 shots

ing over the die cavity region. If failure is not obtained on the first shot the plate is returned to the temperature control box for re-equalization to the desired temperature. This process is repeated until a weld failure is obtained or to a limit of four shots if failure is not developed. The test sequence causes an increase in bulge deformation (measured as depth of bulge or thickness reduction of the plate) in reproducible steps. If failure is not developed on the first shot a thickness reduction (TR) of the plate (simplest method of measuring deformation) of 3% is reached, following the second, third and fourth shots the TR is 6, 9 and 14%, respectively. On development of a failure the TR obviously will be of a level which is in the range between the levels of the final and previous shots; for example, a failure obtained on the third shot will fall between 6 and 9% TR. Actual measurements of TR were made for all test plates to determine

Fig. 7 Illustrating excellent performance of weldment with weld ripple removed

the exact level of deformation at which the failure occurred.

The tests are conducted over a series of temperatures to establish the range over which the weldment looses its ability to develop extensive deformation prior to failure. The method represents a ductility transition test for a full thickness weldment. The performance criterion of prefracture deformation is basically of the same type as the prefracture lateral contraction criterion (ductility) used for the evaluation of weldability tests of the Lehigh and Kinzel type.

Figure 4 illustrates the result of the bulge tests for the peened and for the as-welded test plates. The peened plates in all cases failed on the first shot. At temperatures in the range of 40 to 80° F the plates remained almost flat and the TR was barely measurable (1% or less); in the range of 100 to 160° F a slight bulging and TR of 2 to 3% was observed. This increase

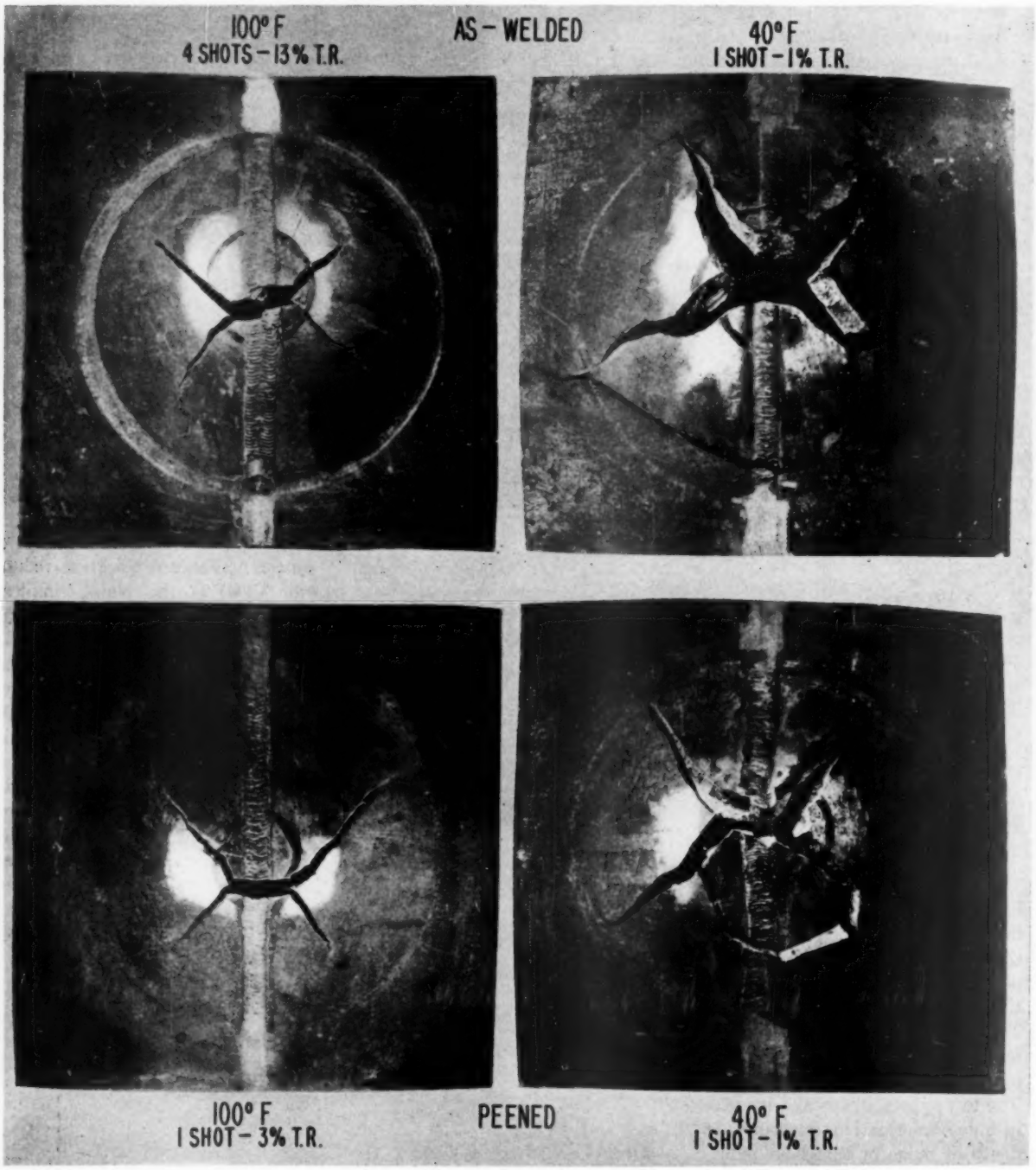


Fig. 8 Illustrating that plate properties determine the extent of fracture while weld properties determine whether the starting of fracture is easy or difficult

is believed to be due primarily to the difficulty of initiating a fracture in the base steel at these high temperatures, as will be discussed. The as-welded plates showed a transition from low to high levels of deformation in the range of 60 to 100° F. With the exception of three low values (1 shot failures) obtained at 40, 60 and 80° F all of the as-welded plates demonstrated a convincing superiority over the peened plates. Figure 5 illustrates the extensive bulging which is developed in the case of weldments which required 4 shots for failure.

In the course of testing the as-welded series it was observed that sharp ripples in the welds appeared to act as notches. Figure 6 illustrates the nature of the ripples. The point of failure of the 80° F test (1 shot, 2% TR), for example, was at a particularly sharp ripple. This observation suggested the evaluation of the performance of as-welded plates in the absence of the ripples. Accordingly, the weld reinforcement of two plates was removed by grinding flush with the plate surface. The subject plates were tested at 40 and 80° F and withstood 4 shots (14% TR) *without* failure, Fig. 7. The improvement which was obtained is of particular significance for the 40° F test inasmuch as the previous test with the weld ripples developed failure at approximately 1% TR. It is concluded that the presence of sharp weld ripples is damaging to the performance of the weldments. If feasible, a grinding operation should be performed to remove ripples of the sharp notch variety.

One plate of the peened series was tested with the reinforcement removed to investigate the effect of the weld material which was most heavily cold worked. Approximately $^1/_8$-in. of the weld was removed by this operation and, as indicated by the hardness data of Fig. 2, this resulted in removing all of the material which showed more than 30 to 40 VPN hardness increase. The plate was tested at 80° F and withstood 3 shots

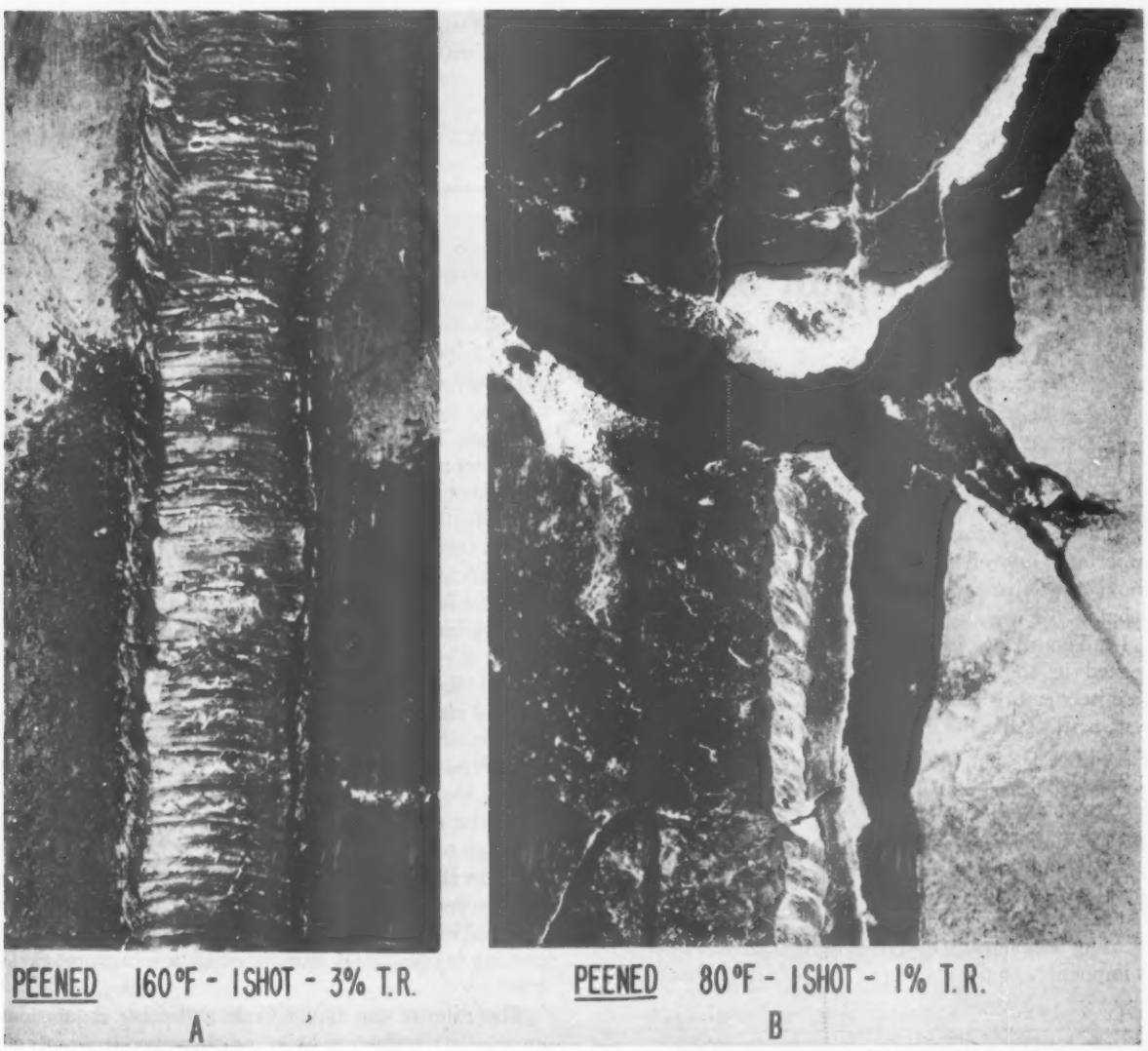


Fig. 9 Illustrating the profusion of brittle cracks developed in the peened weld at all temperatures of test. At 140 and 160° F the plate refused to fracture; at 120 and 100° F short fractures were developed (see Fig. 8); at 80, 60 and 40° F the extent of fracture increased progressively with decreasing temperature

(9% TR) prior to failure. Inasmuch as all prior tests of peened welds showed failures on the first shot it may be concluded that the damage zone is localized to the surface layer of the weld and that it may be removed by a simple grinding operation or possibly by a cover pass.

Previous Explosion Bulge Test investigations of mild steel weldments have demonstrated that while weld properties control the level of deformation at which failure of the weldment occurs, the extent of the failure is determined by plate properties. Figure 8 illustrates the nature of fractures obtained at 40 and 100° F for the peened and the as-welded plates. At 40° F the plate is readily susceptible to fracture propagation as indicated by the extensive breakage. At 100° F fracture propagation is difficult and both weldments developed localized fractures. The inferiority of the peened weld is demonstrated by the fact that weld failure occurred at 2% TR (1st shot) while the as-deposited weld resisted fracture to 13% TR (4th shot).

At 140 and 160° F numerous fractures occurred in the surface of the peened weld but, as shown in Fig. 9A, there was no extension of the failures to the base plate. This is due to the fact that while the peened weld is brittle even at this high temperature the plate is entirely resistant to brittle fracture (above its fracture transition). Previous experience has shown that continued loading following a weld failure at a temperature above the fracture transition of the base plate results only in the development of short, shear tears. The peened weld developed a great number of cracks at all temperatures of test. Figure 9B shows the case for a 80° F test; in this case it is observed that three of the weld cracks competed as "source" points for the brittle fracture of the plate.

These data illustrate that a heavily peened weld is a highly efficient crack starter and will serve to introduce a profusion of cracklike notches into the weldment. Whether or not the presence of such severe notches results in the collapse of the weldment is determined by the properties of the base steel. Unfortunately, our present structural steels are highly sensitive to the presence of notch defects, particularly at temperatures of "cold" service (below 60° F). Thus, peening of the last layer of weld metal should be considered a dangerous practice which greatly increases the hazard of the initiation of brittle fractures in the base steel.

[1] Calamari, P. L., Crum, F. J., and Place, G. W., "An Investigation on Peening," THE WELDING JOURNAL, 32 (8), Research Suppl., 387-s (1953).

An Investigation of Peening

Discussion by Louis J. Larson

THIS PAPER IS very timely and interesting. The authors are to be commended for an excellent report on a well-planned test program.

The data presented by the authors furnish very important information concerning several questions about the effects of peening which have long been debated. The data presented indicate that:

1. The surface of either base metal or weld metal, peened in the manner used in these tests, is very definitely embrittled. Stress relieving at 1150° F after peening the surface is not always effective in eliminating the damage to the peened surface.

2. Depositing a layer of weld metal over the peened surface completely restores the notch toughness of the peened material.

3. There is no advantage in trying to peen the weld metal as hot as possible. Up to a temperature of 900° F the damaging effect of peening increases with increasing temperature and from a practical standpoint it is impossible to peen welds at temperatures above 900° F.

These findings are very gratifying and agree with the opinions of many of those who advocate and use peening. It has long been the belief of most welding engineers and metallurgists that the finishing pass of a weld should not be peened. Recently I had the occasion to observe the Magnaflux inspection of a welded structure which is now in service. While Magnafluxing the welds, we observed Magnaflux indications in the base metal adjacent to one of the welds. A more careful examination showed that the surface of the plate had been peened at this location. We ground the surface smooth and slightly below the original plate surface and found that there were still a number of short cracks in the plate. These cracks were obviously due to peening the surface adjacent to the weld. Although the cracks were small they would be serious in a structure subjected to repeated stress or to impact loads.

It has also been the opinion of those who use peening that no permanent damage is done to the metal by any reasonable amount of peening and that the effect of peening is completely eliminated by a subsequent weld bead.

The rules of the Boiler Code and other regulations governing peening are based on these two assumptions and the correctness of the regulations is verified by the data presented by the authors.

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Paper by P. L. Calamari, F. J. Crum and G. W. Place was published in the Supplement to THE WELDING JOURNAL, 32 (8), 387-s to 402-s (1953).

On the question of peening hot vs. peening cold, below 150° F, there have been many discussions. These tests show that so far as damage to the metal is concerned, peening hot is more harmful than peening cold, but if another layer of weld metal is to be deposited, the embrittlement due to peening will be eliminated in either case. The question of whether peening hot is more effective in decreasing the stresses due to welding is not answered by this investigation. However, if the metal is peened too hot it will develop stresses again after peening while cooling down to the temperature of the base metal and in that respect peening hot is less effective than peening cold. In most large weldments where peening is likely to be used, the peening is ordinarily done after the weld cools to temperatures approximating the interpass temperature and from the data presented this practice appears to be as good as any.

The amount of peening used in these tests, even for the samples which were fast peened, is greater than that normally used on production work. The area which was peened in these tests was apparently about $^1/_8$ in. wide. For a weld $^1/_2$ in. wide, the rate of travel for a corresponding amount of peening would be approximately 5 ipm, and for a 1-in. weld it would be 2 $^1/_2$ ipm, which is heavy peening compared to that normally used on a production weld. The specimens which were peened at 5 ipm were peened very heavily compared with most production welds. This might be expected to cause flaking of the material and possibly produce small cracks in the surface which may account for the fact that the specimens which were slow peened were not improved by stress relieving at 1150° F.

It is interesting to note that the peening tool adopted for these tests is practically the same as that normally used on production work. It has been found by experience that a round tool of sufficient size to prevent punching holes in the metal is not effective for peening in a weld groove. With a round tool it is practically impossible to peen the metal near the side walls of the groove.

The data shown in Fig. 3 on the calibration of peening hammers appear to be more consistent and logical than some previously published. These data show no reduction in the effectiveness of peening by using even the heaviest riding loads on the hammer. The only surprising values are those for the middle-sized hammer with zero riding load at 75 and 90 psi pressure. It is hard to understand why the energy under these conditions should be greater than that with a 50-lb riding load. Experience on production welds indicates that it is necessary to hold the hammer down with some pressure in order to obtain effective peening. From the data in Fig. 3 it does not appear that air pressure is too critical although obviously the pressure should not drop far below the normal 90 lb used in most shops. It is gratifying to note that the conditions normally used for peening welds are very effective in producing the desired effects.

This investigation indicates the harmful effects of peening improperly done and shows how the damage done by peening can be eliminated. However there is no direct indication that peening is beneficial. The advocates of peening base their opinion on shop experience which they believe shows conclusively that peening is a great help in preventing cracking and reducing distortion during the welding of heavy structures. I have seen many structures which developed cracks in or adjacent to the weld and which were later rewelded without difficulty when the welds were properly peened. I have also used peening to control deformations caused by heavy welds to within a very few thousandths. Since these are the primary reasons for peening welds it is felt that the use of peening can be very helpful in many cases.

The data presented by the authors on dimensional changes due to peening are an indirect indication of how peening can be used to control distortion. The transverse displacement of the metal on a 2-in. gage length across the weld, due to peening in the manner described, was over 0.010 in. on the top surface and only slightly less on the bottom of the plate. Thus by peening only a narrow area on the top surface of a $^1/_2$-in. plate it was possible to stretch the full thickness of the plate by this amount. Obviously, by peening the full width of every layer of weld metal it is possible to greatly reduce and possibly eliminate the transverse shrinkage due to welding. If the shrinkage of the weld metal is reduced, the distortion of the structure and the stresses produced by welding are also reduced. These findings are consistent with observations of the strains in base metal adjacent to welds. Measurements of such strains, using strain gages, have indicated that the strain in the base metal adjacent to the weld can be reduced by peening to only a small fraction of the strains in similar structures produced by welding without peening.

Authors' Reply

The authors wish to acknowledge with thanks Mr. Larson's very informative and practical discussion of their paper. It is agreed that the amount of peening used on the laboratory specimens with the peening machine was more severe than would normally be used in manual production peening. With a single peening pass at the fast rate of travel (20 ipm), it was found necessary to peen severely in order to produce a peened notch of sufficient depth for the impact specimens. Moreover, it was felt that any ill effects on the physical or metallurgical properties could be more readily determined if the specimens were severely peened.

When the chisel-shaped peening tool was first adopted, it was found that the amount of flaking appeared to be associated with the degree of relief at the leading edge of the tool, as well as the speed of travel. For the slow travel rate (5 ipm) the peening tool was relieved sufficiently so that flaking was practically negligible. The discussor has suggested that small

cracks associated with the flaking might be responsible for the failure of the 1150° stress relieving treatment to improve the properties of peened weld metal. The authors have to advise that microscopic examination at 1500 × on several random weld samples which had been peened at room temperature and then stress relieved at 1150° F failed to disclose the presence of microcracks. It might also be pointed out, as shown in Figs. 35 and 36 of the report, that this stress-relieving treatment had practically no effect on the hardness of peened weld metal.

With regard to the peening hammer calibration data, Mr. Larson has pointed out that slightly higher energy values are shown for zero riding load than for 50-lb riding load when using the medium hammer at 75 and 90 psi air pressure. The authors only explanation for this is that during these calibration runs with zero riding load an excessive reciprocating motion of the hammer itself was observed. The resulting blips on the oscilloscope screen therefore varied considerably in height depending on the relative motions of the hammer and the tool at the time the blow was delivered to the calibration box. It may well be that most of the pictures of these blips, since they were taken at random were taken when the hammer and the tool were acting together to increase the energy of the blows. This excessive up and down motion of the medium hammer with zero riding load did not occur when the actual grooves were peened in the prime plates and welds nor did it occur during any of the other calibration tests.

Pressure Vessel Research in the Universities

(*Continued from page 70-s*)

the plastic range for design pressure as affected by the number of life cycles of the vessel.

We have studied various types of stress raisers such as notches, surface defects, welding and welded nozzles. We have established the effect upon life cycles for these conditions.

We have developed three types of tests that duplicate conditions in pressure vessels:

1. Biaxial bend tests in full thickness specimens at Lehigh.
2. Biaxial pressure tests on flat-plate full-thickness specimens at the University of Illinois.
3. Tests on model vessels with stress raisers at École Polytechnique.
4. Theoretical analysis of concentrated stresses due to supports at Cornell.
5. Theoretical and test analysis of concentrated stresses at head junctions at Purdue and Standard Oil of Indiana.

We have covered parameters of materials, fabrication, and design. We have covered low-temperature conditions. We propose to investigate high-temperature conditions up to 650° F with a fall-off in yield strength and Young's Modulus. In the coming year we shall investigate steels with yield strengths of 70,000 to 90,000 psi and tensile strength of 100,000 to 120,000 psi.

While we have eliminated corrosive conditions to simplify our research, it is recognized that for the oil industry and chemicals this may be a necessary factor. A study of the effect of corrosion may be a necessary problem in the future.

A coordinating committee has been appointed consisting of the directors of research projects at Lehigh, Illinois and École Polytechnique to draw conclusions from the work at these institutions. Included in this committee are the chairmen of the project committees at these institutions, all from industry. It is expected that during the next two years this joint committee will present, for publication, conclusions that may be used by designers, fabricators, and Code writing bodies as the result of PVRC research.

We have been greatly impressed with the results of cooperation among several university research laboratories and industry. Such cooperation and correlation has been most satisfactory and productive. It leads me to conclude that hit-or-miss individual research in university laboratories, such as for doctorate degrees, which may result from individual interest or decision as to what should be investigated, may be of unexpected value in long-time trends but in general may be less valuable to scientific progress and early application than guided research for a common objective.

There are certain fields in Science that should have priority from practical need. It is recognized that fundamental science requires individual effort that should not be inhibited. But on the other hand, there is much to be done to fit in with required practical research that can be used to advantage without delay. Academic research can profit by such guidance.

Field-Weld Test for Mild Steel Welds at Low Temperatures

A simulated field weld test specimen requiring no notching or machining

by John R. Watt and James J. Smetana

INTRODUCTION

THE authors believe that much current literature about welds at low temperatures is incomprehensible to most active welders and their supervisors. A simpler test, analogous to actual welds in the field, seemed desirable.

Consequently, the following tests were made using specimens requiring little preparation, no notching, and no machining. The weld beads were left intact as in real welds.

MATERIALS

To further popularize the subject, common steel and electrodes were used. The steel furnished by the Jorgenson Steel Co. of Houston was Universal Mill Plate 1/4 in. thick and 12 in. wide. Of SAE 1020 classification, its chemistry and properties were as follows:

C	0.24
Mn	0.42
Phosphorus	0.016
S	0.030
Yield point, psi	38,340
Elongation, %	31
Tensile strength, psi	61,670

This steel was cut transversely into 4- x 12-in. test plates in preparation for the welding.

The 5/32-in. diam electrodes were furnished by several firms. The following were used in these tests:

Class E6010. Of organic coating, these created weld deposits of approximately C 0.07, Mn 0.47, Si 0.22 and S 0.03.

Class E6016. These low-hydrogen rods of potassium type yielded deposits of approximately C 0.10, Mn 0.50 and Si 0.49.

John R. Watt is Associate Professor of Mechanical Engineering, University of Texas, Austin, Tex., and **James J. Smetana** was Research Assistant, University of Michigan, Ann Arbor, Mich. He is now employed by the General Electric Co.

Presented at the National Spring Meeting held in Houston, Tex., June 16-19, 1953.

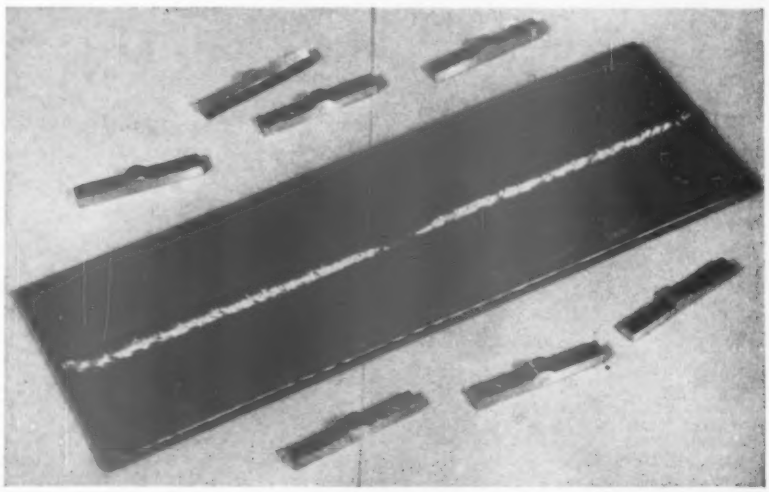

Fig. 1 The bead is welded upon the test plate at 90 deg to the "roll" of the steel. The specimens are 1/4 x 1/4 in. in cross section and are unnotched

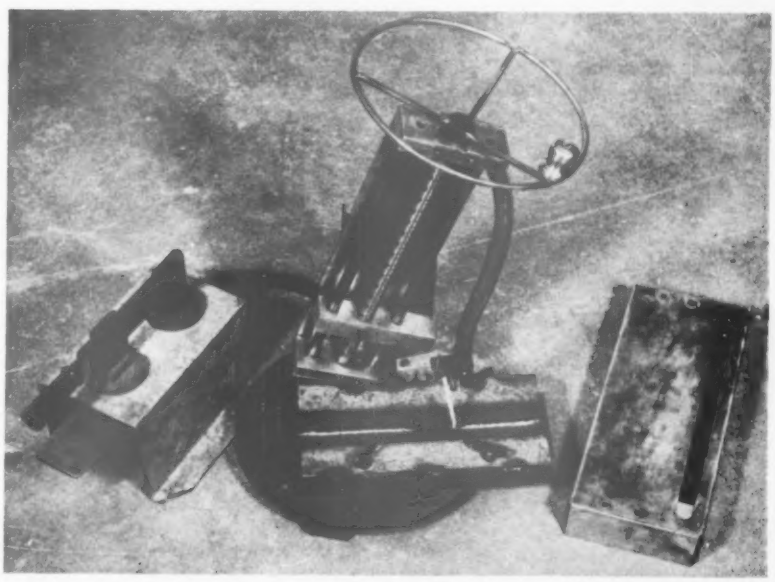

Fig. 2 Semiautomatic welding head allows close control of bead after adjustment to suit burndown rate of electrode

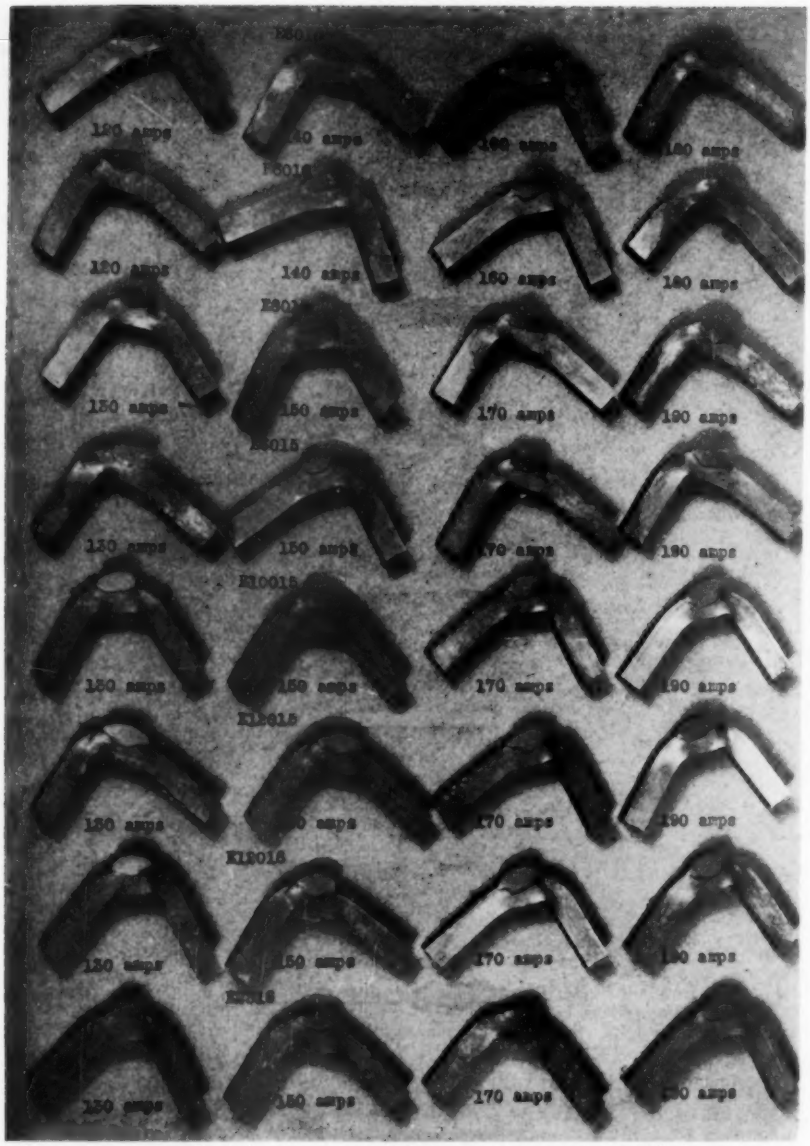

Fig. 3 Due to bead reinforcement, at 94° F room temperature welded specimens absorbed slightly more energy than did unwelded ones. Illustration includes specimens from other tests

Class E6015. These low-hydrogen rods of sodium type deposited metal of approximately C 0.08 and Mn 0.70.

All electrodes were new and undamaged. They had been stored together, so moisture contents were relatively the same.

SPECIMEN PREPARATION

The extreme ends of each plate were removed beforehand to provide 16 unwelded test bars for control purposes.

Specimens were made by running a single bead down the center of the 12 x 4 test plates. This placed the bead at 90 deg to the roll of the steel. See Fig. 1. Welding was done by a skilled welder using a semiautomatic welding head used in other experiments. See Fig. 2. This device compensated for burn-down rate and allowed laying down extremely uniform beads.

The welds were made at four current settings, the welder adjusting manually to get beads of equal size.

The beginning and ending 1 in. of each bead plate was discarded and the remainder sawed into transverse specimens about $^1/_4$ in. wide. These were not machined or notched in any way. The cut surfaces were ground smooth on a magnetic grinder, and the specimens sawed to Charpy bar length. All specimens were marked to indicate their identity.

A total of 192 weld test specimens was made, or 16 for each current setting for each electrode. These were chosen from varying positions in the test plates to ensure fair sampling.

THE TEST

Two questions were being investigated: First, the comparative impact strengths of welds from the three electrodes at low temperatures; and second, the effect of welding current settings upon the low-temperature impact properties of metal from the same electrodes.

The appropriate welded and unwelded specimens were first tested at room temperature, 94° F, typical tested bars being shown in Fig. 3 along with samples from other tests. The others were chilled in alcohol and dry ice baths maintained at −3, −50 and −109° F. The refrigerated bars were then withdrawn one by one, inserted into the standard impact testing machine and immediately broken like Charpy bars. The intervening rise in temperature has been shown by other investigators to be negligible.

The bars were inserted so the hammer struck on the side opposite from the weld, thus placing the bead in sudden tension.

THE RESULTS

The comparison of the E6010, the E6016 and the E6015 electrodes is shown in Table 1. Readings are in ft-lb of absorbed energy.

Table 1

	° F			
Amp	*94*	*−3*	*−50*	*−109*
E6010—Averages of 4 specimens each				
120	63	68	39	2
140	65	72	37	2
160	67	75	30	23
180	68	66	38	28
E6016—Averages of 4 specimens each				
120	69	63	72	9
140	62	71	73	18
160	72	71	70	33
180	67	84	73	43
E6015—Averages of 4 specimens each				
130	62	69	56	2
150	64	63	54	6
170	63	65	36	4
190	64	73	75	7
Unwelded specimens—Averages of 4 specimens each				
	63	68	75	81

See Figs. 4, 5 and 6 for typical specimens after testing at −3, −50 and −109° F, respectively.

To summarize, the three electrode materials behaved about as follows:

(averages of 16 bars, disregarding welding current differences):

	° F			
	94	*−3*	*−50*	*−109*
E6010	66	70	34	14
E6016	67	72	72	26
E6015	64	68	55	4
Unwelded	63	68	75	81

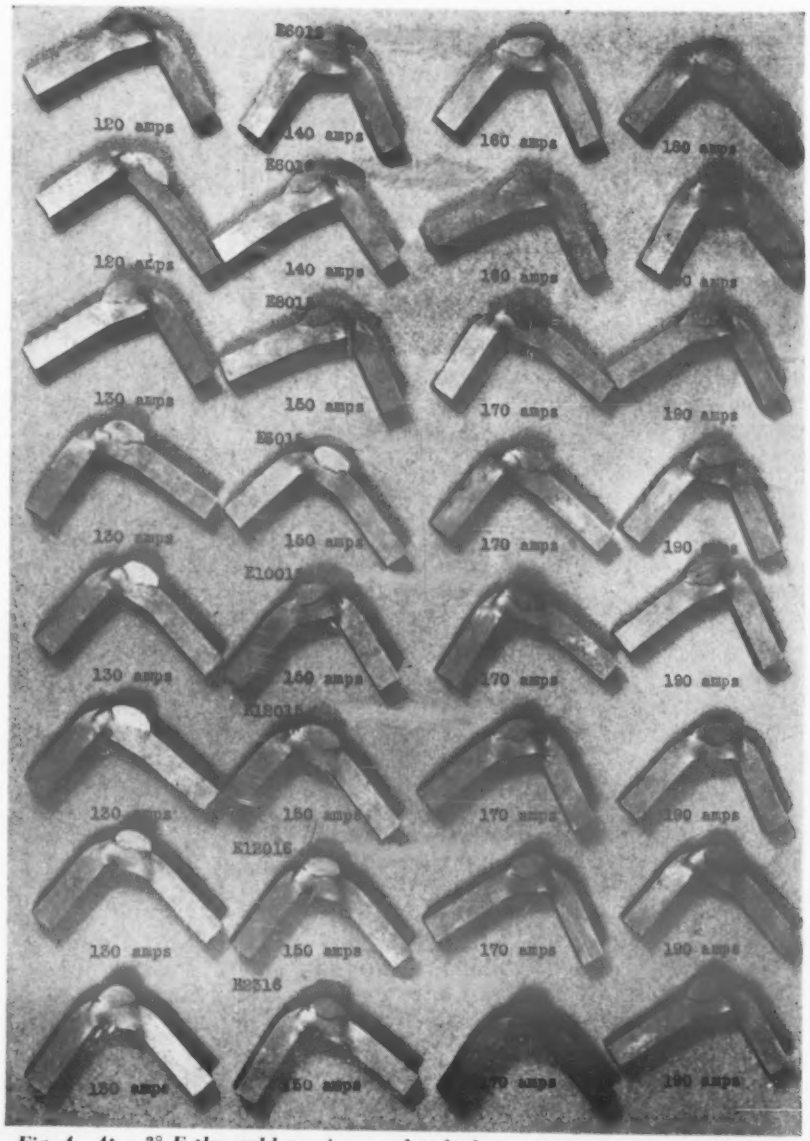

Fig. 4 At −3° F the weld specimens absorbed more impact than at 94° room temperature. The occasional fractures were all of ductile type. Illustration includes specimens from other tests

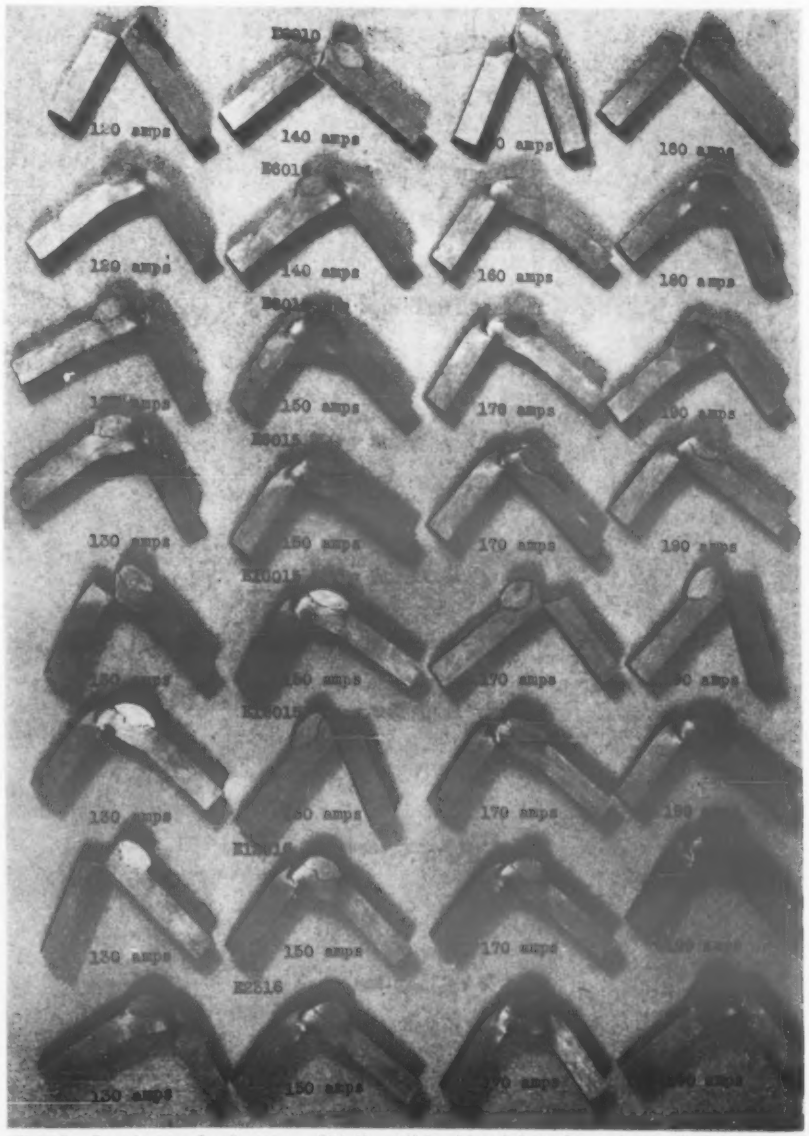

Fig. 5 Specimens broken at −50° F exhibited both brittle and ductile fractures with impact strengths unaffected by welding current settings. Figure includes specimens from other tests

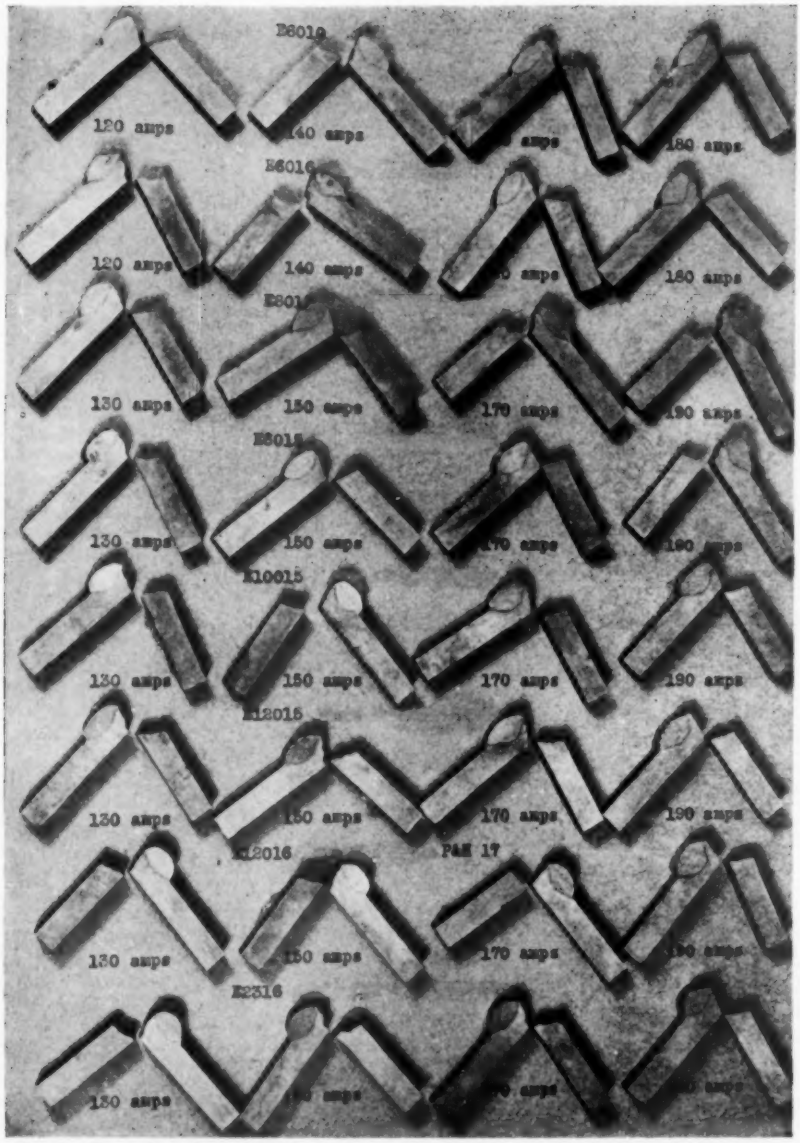

Fig. 6 Virtually all weld specimens tested at −109° F exhibited brittle fractures, their impact strengths varying with the welding current employed. Figure includes specimens from other tests

At the refrigerated temperatures of −50 and −109° F many specimens fractured either ductilely or brittlely, all fractures originating at the edge of the bead. In ductile failure, the metal first tore away laterally from the weld and then doubled back toward the point of impact. These fractures were unmistakably fibrous and irregular. See Fig. 5.

In brittle failure the fractures progressed directly from their origin on the weld side of the bar in a straight line to the other side.

At 94 and −3° F, no brittle failures occurred. But at −50°, 7 of 16 E6010 bars showed it, against none for the E6016 and 3 for the E6015.

At −109°, 13 of 16 E6010 specimens had brittle fracture, and 9 of the E6016 bars. The E6015 welds all failed in brittle fashion.

None of the unwelded specimens showed any sort of fracture. They deformed in bending enough to be thrown from the machine but were totally intact and sound.

CONCLUSIONS

1. So long as unnotched or unwelded, the SAE1020 base metal in $\frac{1}{4}$ x $\frac{1}{8}$-in. sections exhibits little or no cold embrittlement down to −109° F.

2. Using half of their room temperature impact values as transition points, the three electrodes tested here show rough transition temperatures as follows:

E6010	−58° F
E6016	−98° F
E6015	−84° F

3. The difference in the welding current settings had no visible effects except at −109°. Here, in every case, the greater the current the greater the impact resistance of the weld.

ACKNOWLEDGMENT

The authors thank the Jorgenson Steel Co. of Houston, the Air Reduction Sales Co., the Alloy Rods Co., the Arcos Corp., the Harnischfeger Corp. and the McKay Co. for the materials donated for use in these and other experiments.

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Factors Which Influence Weld Hot Cracking

High-temperature alloys are susceptible to hot cracking and require close control of welding procedures to prevent hot cracks

by W. R. Apblett and W. S. Pellini

Abstract

The development of hot cracks in welds results from the combined effects of metallurgical and mechanical factors. Metallurgical factors relate to conditions of solidification of the metal, the grain size, presence of low-melting eutectic films, etc.; mechanical factors relate to conditions of strain (extension) developed in the weld metal during solidification as the result of differential cooling at various weld and near-weld positions. A hot cracking test was developed which evaluates the hot cracking susceptibility of weld deposits in terms of the severity of the mechanical conditions which are required to produce hot cracking. It is demonstrated that certain high-temperature alloys are inherently susceptible to hot cracking because of unfavorable conditions of solification; such alloys require close control of welding procedures to prevent hot cracking.

INTRODUCTION

THE very high temperature gradients which exist in jet engines, gas turbines and similar power units require that a gradiation of alloys must be joined together by welding. In many cases superalloys are joined to high-temperature alloys and these, in turn, to moderately heat-resisting alloys.

Many applications of this type are made difficult by the problem of hot cracking. One particular application is the welding of buckets to the rim of turbine wheels, superchargers, etc. This specific type of hot cracking is called notch extension cracking. Figure 1*A* illustrates this defect. Other defects of the hot cracking type encountered in welding of high-temperature alloys are illustrated in the remaining illustrations of this figure. Root cracking and cracking which extends from grain boundaries of coarse-grained materials are particularly troublesome. A review of the incidence of various types of hot cracks has been presented by Poole[1] for Type 347 stainless steels. He reported that control of analysis, particularly with respect to C to Si ratio, has resulted in a substantial reduction of such cracking, and that control of welding procedures entailing preheating, careful fit-up, use of small diameter electrodes, string bead techniques in root passes, etc. were considered to be beneficial by various fabricators. However, despite the various empirical procedures which have been developed the problem remains a difficult and severe one.

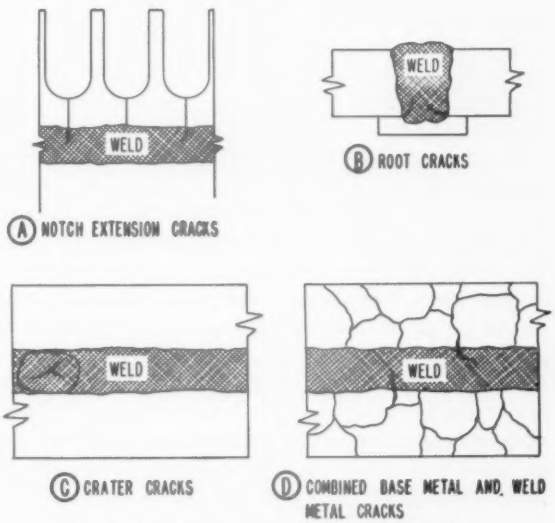

Fig. 1 Various types of hot cracking defects

It is the general consensus of those who have investigated this problem that basic data concerning the nature of the defect and of the important variables which determine its occurrence are prerequisite to a direct approach. Foremost, it is essential to develop tests which reproduce the production difficulties so as to permit systematic investigation of variables.

This investigation is concerned with the development of such a test and with the evaluation of metallurgical and mechanical variables which have been shown to be important in determining the occurrence of similar types of hot cracking defects (hot tears) in castings.

MECHANISM OF HOT CRACKING AS DEDUCED FROM CASTING STUDIES

Studies conducted at this Laboratory by means of simultaneously following the solidification of castings by thermal analysis and radiography to determine the

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Presented at the AWS National Fall Meeting, Cleveland, Ohio, Oct. 20, 1953.

time of cracking have demonstrated that hot tearing occurs at temperatures slightly above the solidus. At such temperatures the metal consists of dendrite structures separated by essentially continuous films of liquid. It was further demonstrated by tensile tests of solidifying castings that the metal does not develop measurable strength until the surface skin approaches the solidus temperature and that an abrupt rise in strength of several thousand pounds per square inch occurs on passing through the solidus. At temperatures slightly above the solidus the fractures are of "square" type, exhibiting no evidence of ductility, and show a dendritic appearance similar to hot cracks. However, on passing through the solidus the metal develops a high degree of ductility as evidenced by large reduction of area prior to fracture and the fracture appearance changes to a ragged fibrous type. Details of the tests, and interpretations of the data are presented in References 2 and 3.

Figure 2 summarizes the essential features of the hot cracking phenomenon as deduced from the casting studies. The sharp changes in load bearing capacity and ductility which are developed in passing through the solidus are illustrated schematically and related to solidification temperature range of the metal. It should be noted from this illustration that during the growth of the dendrite structures (mushy stage of freezing) the metal has nil strength but permits extensive straining prior to fracture; the straining developed at this stage represents extension of the semifluid mass of liquid and solid. Hot cracking develops near the solidus inasmuch as straining which occurs at this

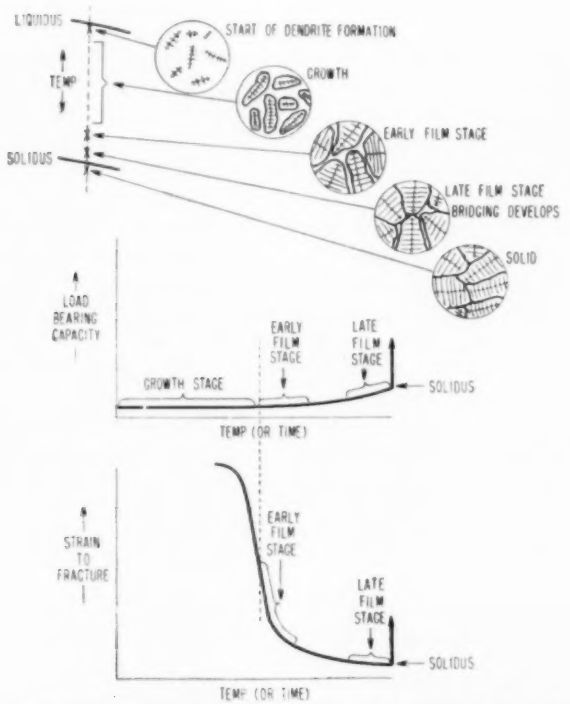

Fig. 2 Mechanism of hot cracking as deduced from casting studies

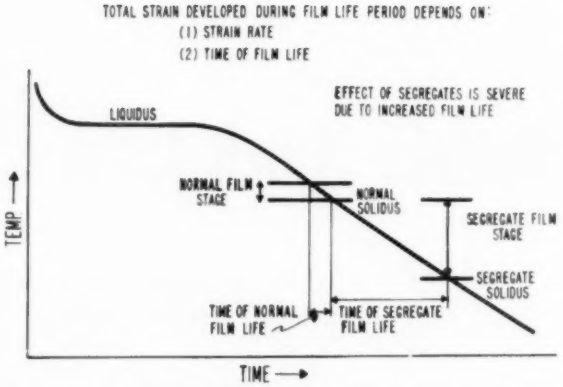

Fig. 3 Low-melting-point segregates located at grain boundaries promote hot cracking by increasing the time that the weld metal remains in liquid film stage

time is concentrated to narrow liquid film regions which do not provide for appreciable separation without causing interdendritic ruptures following the liquid film paths. If the imposed strain is inadequate to cause rupture the metal passes through the solidus and then is no longer able to hot crack due to the absence of liquid films. Thus, hot cracking results when the race between achieving solidity and the imposition of strain on the film-stage metal is won by the straining process.

It is foundry experience that the presence of elements, such as sulfur, which produce low-melting eutectic films greatly increases the tendency of steel castings to hot cracking. In fact when sulfur exceeds 0.05% it becomes extremely difficult to produce castings free from large hot tears. The reason for this behavior, which bears a parallel to weld hot cracking effects of sulfur, is illustrated schematically in Fig. 3. The existence of sulfide films to temperatures considerably below the solidus extends the time of film stage and provides further opportunity for the straining process to accumulate extension in the liquid film regions and thus cause hot cracking.

It was concluded from the casting studies that metallurgical factors which influence solidification conditions provide the necessary conditions for hot cracking; however, its actual occurrence is determined by the severity of the imposed strain conditions. It is well known in steel casting that a given metal composition may or may not hot crack depending on the design of the casting and the yielding characteristics of the sand. These factors basically control the rate of extension imposed on the hot spot during the time it is susceptible to hot tearing. Narrow hot spots, rigid sand, and long regions undergoing contraction promote hot cracking since rapid extension of the hot spot results from this combination of mechanical factors.

A similar interplay of metallurgical and mechanical factors may be visualized at interbucket points, as illustrated in Fig. 4. As the arc passes by two adjoining buckets expansion develops and upsetting may be visualized to occur as the result of the expansion forces.

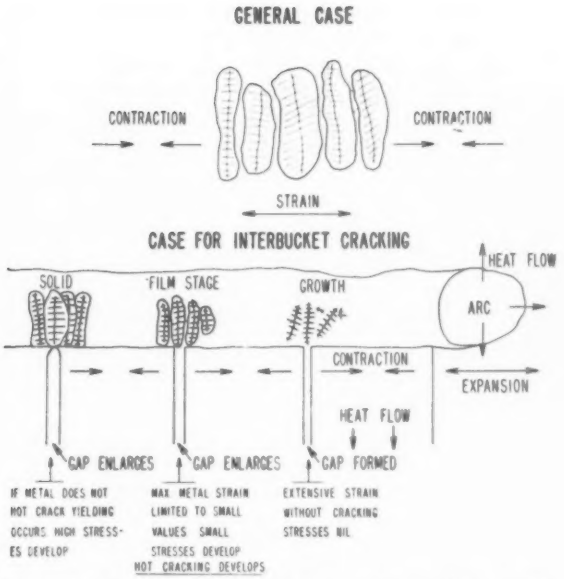

Fig. 4 Mechanism of hot cracking of the notch extension type

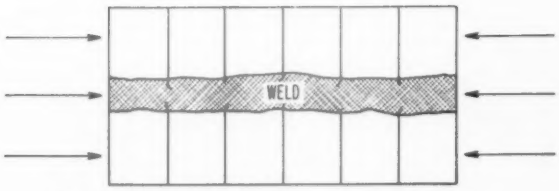

Fig. 5 Assembly of bars for hot-cracking test

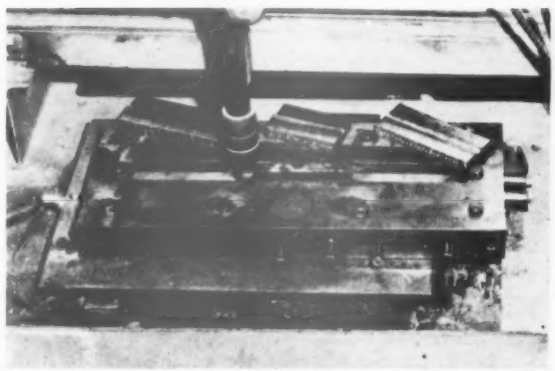

Fig. 6 Welding procedures for hot-cracking test

Then, as the arc moves on leaving behind a molten pool, the buckets shrink, developing a gap which continues to open as the metal solidifies. Hot cracking cannot occur as long as the metal is in a mushy or growth stage since extensive strain is tolerated without fracture. However, as the metal enters film stage the extension developed by the opening-up process causes highly localized strain in the liquid film regions and hot cracking may then occur.

A number of metallurgical factors related to the solidification range of the metal, the type of dendrite structures formed, the presence of film forming elements, eutectics, etc., determine the sensitivity of the metal to the imposed strain. Thus, welding factors which effect the composition of the solidifying weld metal (metallurgical conditions) may be expected to be important. Welding factors which affect the strain condition developed are also important since these factors control the severity of the imposed strain (mechanical conditions).

DEVELOPMENT OF HOT-CRACKING EVALUATION TEST

Ideally, a hot-cracking evaluation test should permit practical control of mechanical and metallurgical variables. Also, the test should be customized to welding conditions and preferably should reproduce production difficulties.

The approach taken in this development was to reproduce interbucket hot cracking which was considered to be representative of the general problem of hot cracking, i.e., straining of nearly solid weld metal. It was recognized that the various types of hot cracking problems illustrated in Fig. 1 entail variations as to degree of severity of straining which is developed. Accordingly, provisions were made to introduce control over this factor.

Figures 5 and 6 illustrate the essential features of the test. Bars 2.5 in. by 0.650 in. by variable widths ($^1/_4$ to

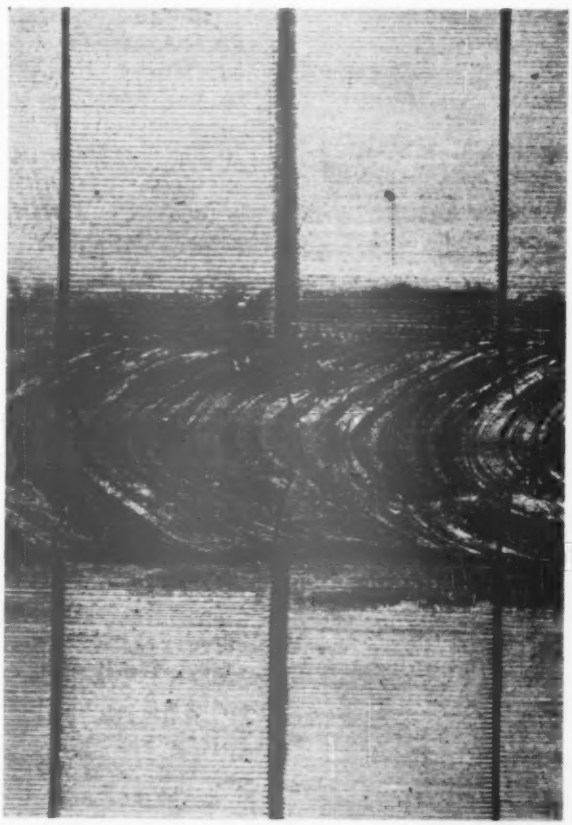

Fig. 7 Results of hot-cracking test for metal of high susceptibility

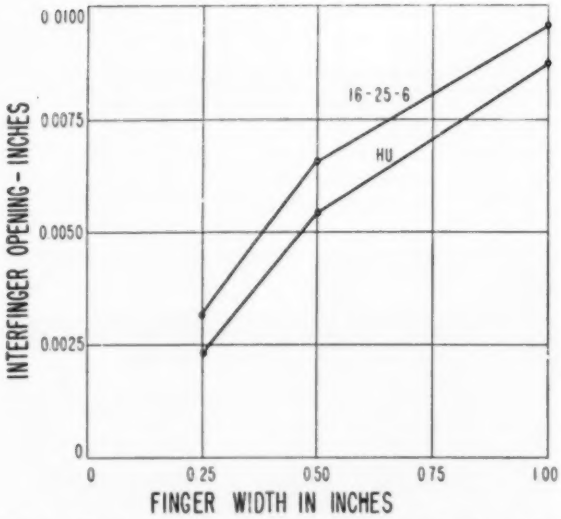

Fig. 8 Illustrating that the final opening developed between test fingers is a function of the finger width

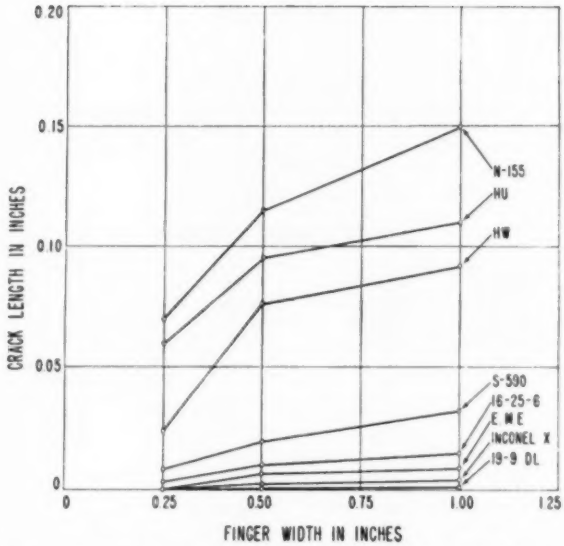

Fig. 9 Extent of hot cracking for various alloys as a function of the severity of mechanical conditions

1 in.) are fitted together tightly in a clamping jig with a fixed pressure established by a torque wrench. A fusion weld or bead weld is then deposited across the assembly. The process of expansion followed by contraction operates as described previously, resulting in cracks as shown in Fig. 7 for metals prone to hot cracking. By the use of bars of different widths it is possible to vary the degree of severity of straining. This results from the fact that the final opening between bars is a function of the width. Figure 8 illustrates the relationship of final opening to finger width for two of the materials investigated. While the final opening in itself is not important to hot cracking it serves as an index of the rate of straining during the critical film stage period of the solidifying metal.

It should be noted that the effect of rate of welding, dilution, type of electrode, etc., may be evaluated directly with such a test by appropriate modification of welding procedures.

INVESTIGATION OF METAL SOLIDIFICATION VARIABLES

The scope of the first investigation conducted with this method was limited to obtaining basic information related to solidification characteristics. For this purpose it was desired to have a weld metal of known composition. Accordingly fusion welds were made by the inert-gas, shielded-tungsten-arc method.

A number of alloys were selected to represent materials currently used for high temperature applications. The alloy and chemical compositions are presented in Table 1. All are wrought materials except the HU and HW alloys which are cast types. A single pass bead-on-plate fusion weld was made across the assembly of finger specimens, as shown in Fig. 5. It was found that differences in the physical characteristics (melting point, thermal conductivity, thermal diffusivity, etc.) of the various alloys precluded the use of any one set of prescribed welding conditions for all test specimens. It was necessary to adjust the welding conditions slightly to strive for a given cross-sectional bead size and geometry. The average heat input was approximately 45,000 joules per inch.

The results of the hot-cracking tests are shown in Fig. 9. The materials tested fall into two general groups, those which crack extensively and those which show little or no cracking. Decreasing the finger width decreases the unit strain imposed on the weld metal during film stage and accordingly decreases the amount of hot cracking which develops. However, it is noted that the relative ranking of the materials with respect to hot cracking characteristics remains the same for the various degrees of severity of the imposed mechanical conditions.

It is known from casting studies that delay in the solidification of hot spots is extremely important inas-

Table 1

Alloy	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Co*	*Mo*	*W*	*Cb*	*Ti*	*Fe*
N-155	0.17	1.67	0.66	21.0	20.5	30.2	...	...	...	...	Bal.
HU	0.66	0.67	1.52	17.2	40.0	0.27	0.12	...	0.22	...	Bal.
HW	0.48	1.13	1.43	17.0	60.3	0.23	0.08	...	0.22	...	Bal.
S-590	0.46	1.20	0.40	20.0	18.7	4.87	1.22	2.20	7.31	...	Bal.
EME	0.15	0.52	0.57	19.5	12.2	...	...	3.15	1.15	...	Bal.
16-25-6	0.09	1.68	0.63	16.3	25.2	...	6.25	...	...	...	Bal.
19-9 DL	0.29	1.00	0.82	19.2	9.0	...	1.34	...	...	...	Bal.
Inconel "X"	0.05	0.48	0.48	14.5	74.5	...	...	...	0.93	2.3	6.8

much as the colder regions of the casting which solidified earlier contract and thus force the hot spot region to extend (strain). In effect the interfinger region of the test piece represents a hot spot inasmuch as the rate of heat extraction at this position must decrease as the opening begins to form. It is probable that the solidus temperature and solidification range should affect the time of existence of the hot spot and therefore the tendency to hot cracking. However, when all of the factors which could act to determine the rate of opening up of the fingers as compared to the rate of solidification of the hot spot are considered (heat diffusivity of the solid metal, heat of fusion, etc.), it must be concluded that this is entirely too complex a matter to be adjudged analytically. In this respect the experimental determination of the effects of solidification range and solidus temperature on hot cracking provided the information which is required.

The liquidus and solidus temperatures of the various alloys were determined by induction melting small, 2-lb heats and recording the cooling curve obtained during solidification. The subject temperatures were determined from inflections in the cooling curves. These data are presented in Table 2 and plotted as a function of crack length in Fig. 10.

It is noted from Fig. 10 that the most extensive cracking is obtained for N155 which has the widest solidification range and lowest solidus temperature. Inter-

Table 2

Alloy	*Liquidus, ° F*	*Solidus, ° F*
N-155	2516	2125
HU	2489	2315
HW	2467	2290
S-590	2435	2380
EME	2600	2428
16–25–6	2548	2440
19–9 DL	2610	2425
Inconel "X"	2498	2395

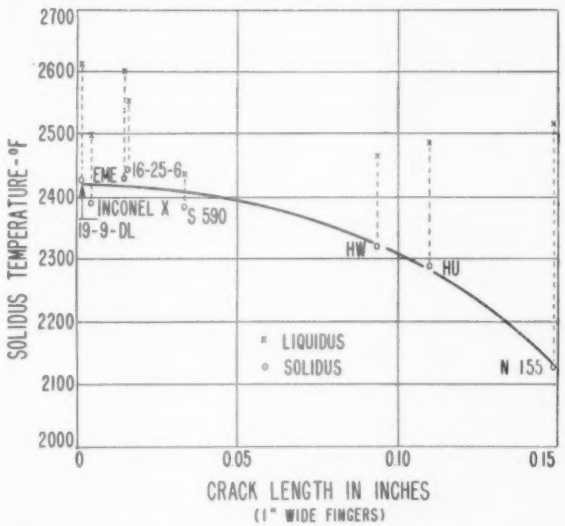

Fig. 10 Relation of crack length to solidification range

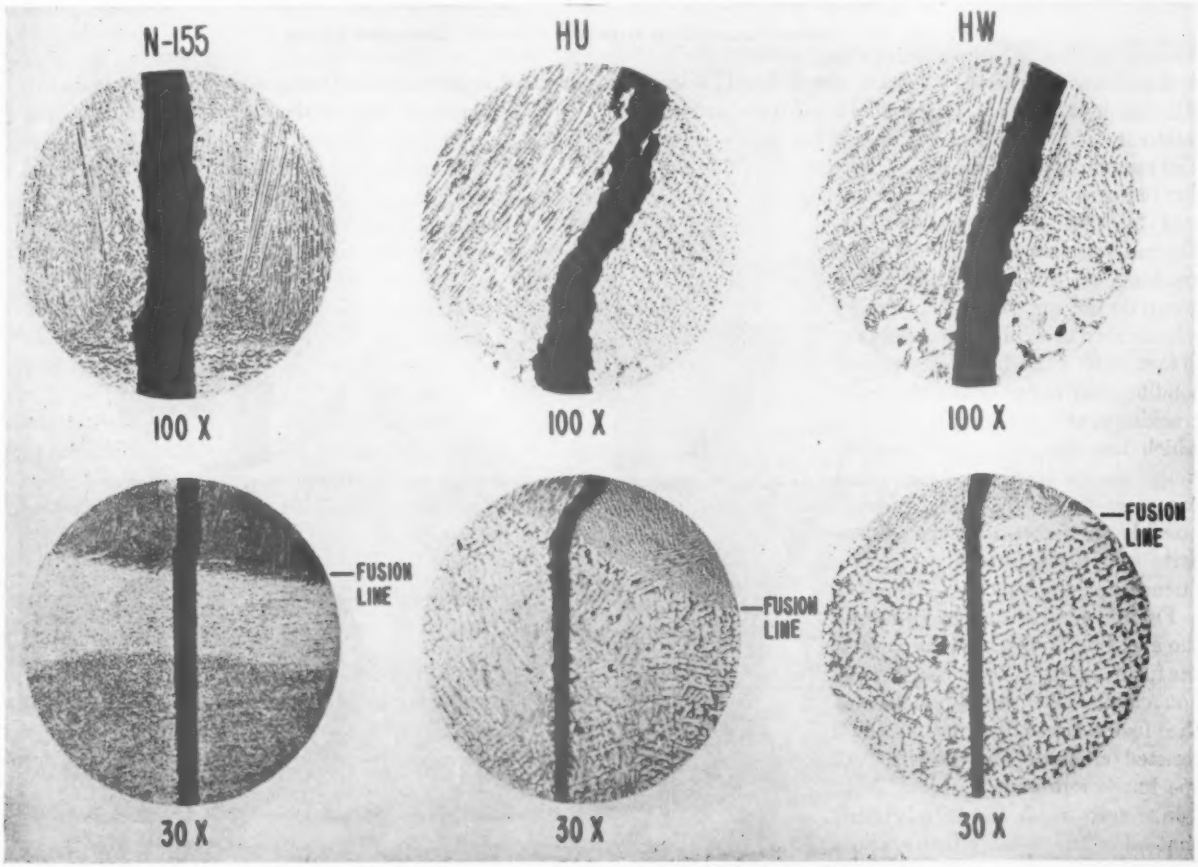

Fig. 11 Photomicrographs of structure at notch-fusion line region

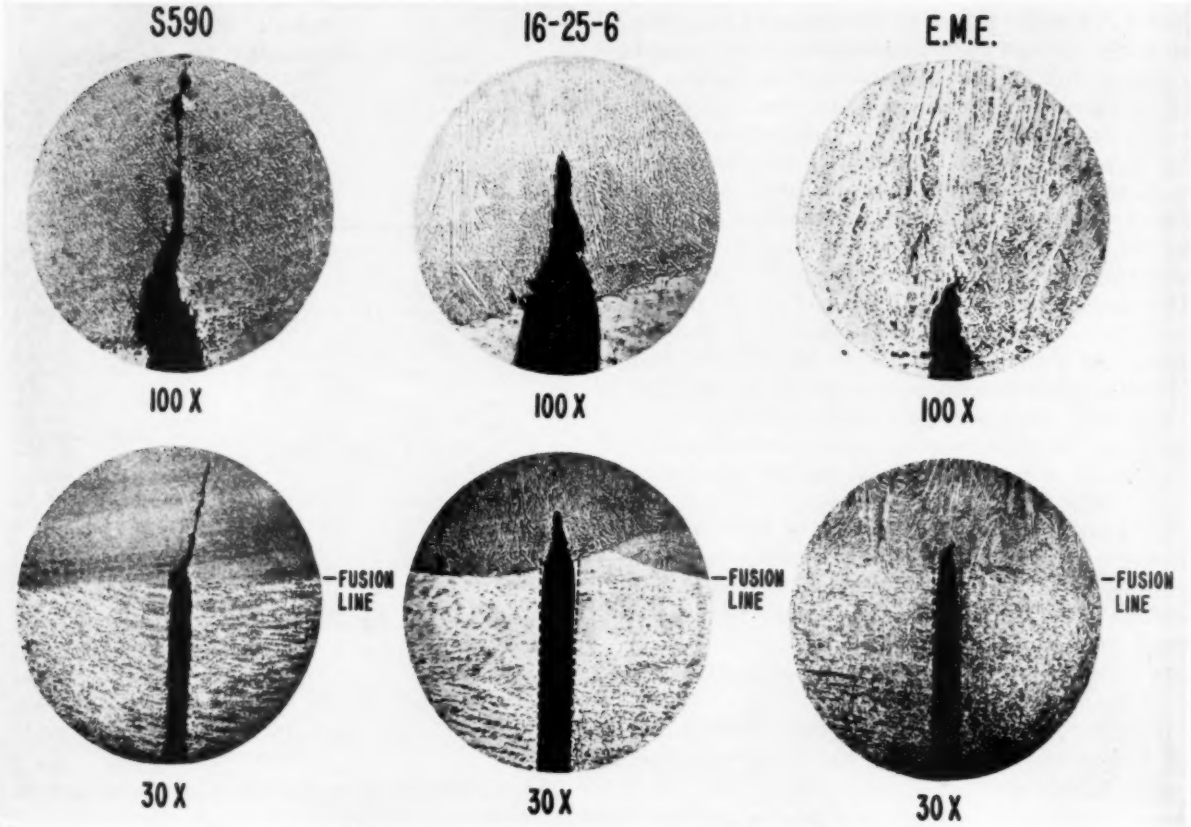

Fig. 12 Photomicrographs of structure at notch-fusion line region

mediate cracking tendencies are noted for HW and HU which have intermediate solidus temperatures and relatively wide solidification ranges. The remaining alloys show high solidus temperatures and are characterized by low cracking tendencies. The relatively small differences in the cracking tendencies of this latter group do not appear to bear a fixed relationship to solidification range—in fact, S590 which has the narrowest solidification range shows the most cracking of this group while 19-9 DL which has the widest solidification range shows least cracking. Apparently, there are other factors, possibly related to the type of dendrite structures formed, which influence hot cracking.

Figures 11, 12 and 13 illustrate the metallographic characteristics of the fusion line area. The path of the hot cracks and the conditions at the fusion line for metals which resisted cracking are evident. All specimens represent samples from 1-in. finger width tests. It is noted that all of the metals which cracked extensively are characterized by pronounced columnar structures; also that there is no evidence of plastic strain of the metal at the fusion line.

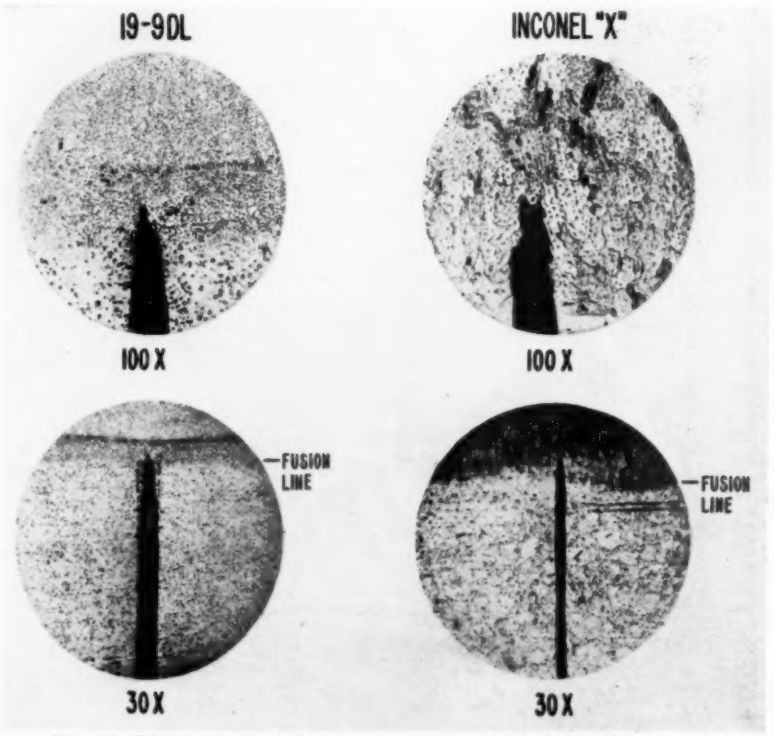

Fig. 13 Photomicrographs of structure at notch-fusion line region

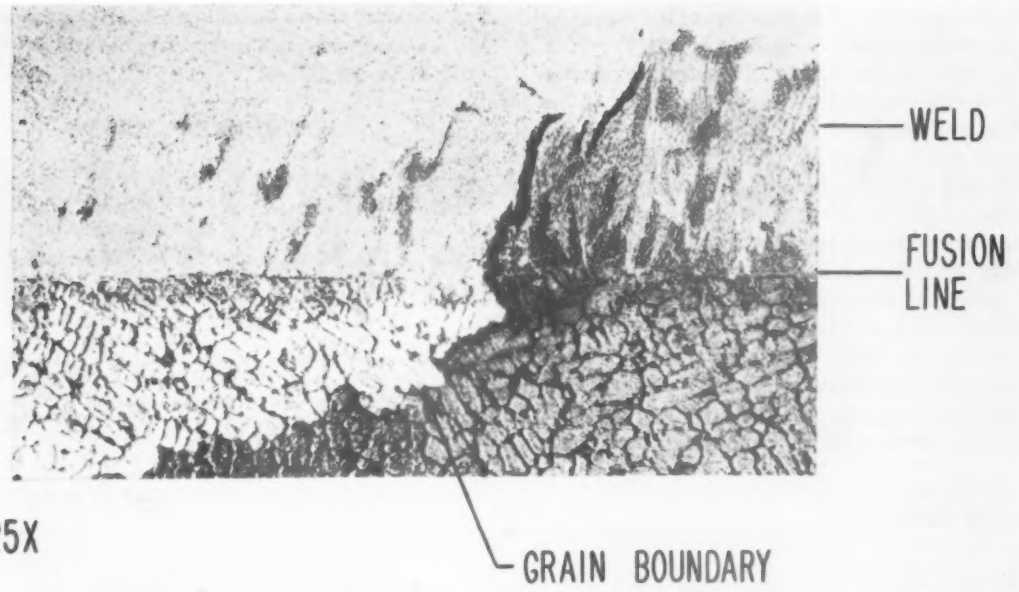

Fig. 14 Illustrating base metal—weld metal cracking in 18–8 material of large grain size (approximately 4 grains sq in.)

Pronounced deformation is observed for metals of high resistance to cracking as noted by a needlelike shape at the fusion line. Inconel X and 19–9 DL which exhibited the greatest resistance to hot cracking show equiaxed structures. The EME alloy is an exception in that it shows high resistance to cracking despite the presence of pronounced dendritic structures. Apparently, the high solidus temperature is the controlling factor for this alloy. These data suggest that susceptibility to hot cracking results from unfavorable combinations of pronounced dendritic structures which provide a semi-continuous liquid path and low solidus temperature which extends the duration of the hot spot. The solidification range appears to be of secondary importance in comparison to the solidus temperature and further study is required to establish its relative significance.

It may be concluded that a metal which is prone to hot cracking does so as the result of straining during a period of essentially nil strength; hence, there is no sign of deformation induced by stressing. A metal which is not prone to hot cracking (because of favorable solidification characteristics) successfully resists the imposed strain during the period of nil strength and then on becoming completely solid flows plastically at the point of stressing.

EFFECTS OF LARGE GRAIN SIZE OF BASE METAL AND PRESENCE OF LOW-MELTING SEGREGATES

Castings and forgings of large grain size associated with the presence of low-melting segregate films are known to present difficult welding problems with respect to hot cracking. It is known that such materials develop cracks which extend from the grain boundaries into the weld proper as shown in Fig. 1*D*. Experiments were conducted with material containing abnormally high amounts of low-melting segregate films to explore this difficulty. Fusion welds deposited on a coarse-grained sample of cast 18–8 and 19–9 Cb containing approximately 0.10% S developed cracks of the type illustrated in Fig. 14. Fine-grain material from the same casting and coarse-grained material which was hot forged did not show these cracks.

This phenomenon is considered to represent a special case of notch extension cracking with the notch formed automatically by the liquation of the low-melting segregates located in the grain boundaries of the base metal side of the fusion line area. Figure 15 illustrates the

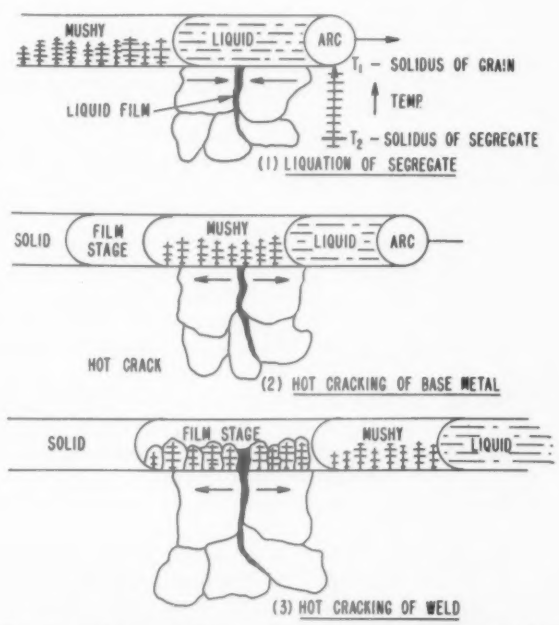

Fig. 15 Schematic illustration of the process of weld hot cracking of the type shown in Fig. 14

mechanism for this case. The liquation of the segregate provides a notch region (the grain boundary) which forms a gap following the passage of the arc in a manner which is analogous to the interfinger separation of the hot-cracking test specimen.

Fine grain size decreases or entirely eliminates this effect by virtue of redistribution of the segregate resulting from hot working or finer as-cast grain size. In effect coarse grains are analogous to wide fingers in the hot cracking test and small grains to small fingers. The change in grain size represents changes in the mechanical conditions which affect hot cracking. Changes in welding procedures which affect the severity of the mechanical conditions should be expected to have similar effects. However, it should be noted that it is essential that the hot weld metal be inherently susceptible to hot cracking due to metallurgical factors, otherwise no hot cracking will result irrespective of the severity of the mechanical conditions.

ACKNOWLEDGMENTS

The active interest and support of Dr. O. T. Marzke, Superintendent of the Metallurgy Division, and the assistance in conducting the investigation by D. O. Buker, E. G. Johnson and D. K. Das is acknowledged with appreciation by the authors.

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Stress Distribution and Fatigue Resistance of Alclad 24ST Multiple Spot Welds

Results of fatigue tests of five types of multiple spot welds in the as-received condition and after hydrostatic treatment

by Georges Welter and André Choquet

INTRODUCTION

THE purpose of this investigation* was to extend, by experimental work, the findings on single spot welds[1] to multiple spot-welded joints. The possibility of an improvement of the fatigue resistance of Alclad aluminum alloy 24ST joints consisting of double, triple, quadruple and quintuple spots was investigated and a study of the stress distribution around the multiple spots was made.

Results of fatigue tests with five various types of multiple spot welds in the as-received condition and after hydrostatic treatment are described. The present publication is a summary of our Report No. 308.[7]

B—SPECIMENS USED

The 0.06-in. thick test specimens† used for this investigation were manufactured under normal conditions of welding procedures as laid down under section C; the spots were X-rayed to eliminate faulty welds. Figure 1 shows the arrangements of the spots in the multiple joints, as well as their main dimensions. It may be of interest to note that the width of all specimens was 2 1/8 in., except for the vertical two-spot arrangements having 1 1/2 in. widths and for the five-spot arrangements having a width of 2 1/2 in. The distance for all outside spots to the edge of the sheet was 3/4 in. and the overlap 2 1/8 in., except for the two horizontal spot welds showing 1 1/2 in. and for the weld with five spots having 2 1/2 in. These dimensions might be of some influence on the microdeformations measured at the interface of these joints.

C—WELDING PROCEDURE

The main welding characteristics are as follows:

1. Vapor degreased.
2. Chemical cleaning in standard Nitric-Hydrofluoric acid. Time of immersion: 1 1/2 min. Resulting average faying surface resistance: 10.6 microhms.
3. Welding done on an electrostatic stored energy spot welder under the following conditions:

(*a*) Tips: Two 5/8-in. tips, 3-in. radius dome to 6-in. radius dome.

Dr. Georges Welter is Professor of Applied Mechanics and **André Choquet**, M.Sc., is Associate Professor Strength of Materials, École Polytechnique, Montreal, Canada.

* This investigation has been sponsored by the subcommittee on Fatigue of Spotwelds of the Welding Research Council, New York.
† The samples have been supplied by the Aluminum Company of America, New Kensington, Pa., for which we express our very best thanks.

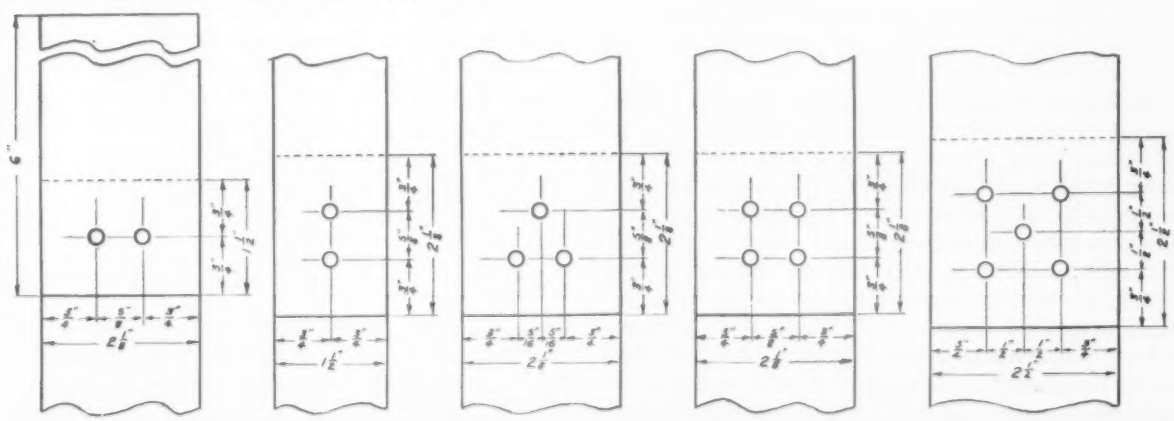

Fig. 1 Dimensions of five different arrangements of multiple-spot-welded joints

(*b*) Tip Force: 2000 lb, a forge force of 2000 lb.
(*c*) Mfds: 2600
(*d*) Volts: 2325
(*e*) Watt Seconds: 7200
(*f*) Transformer Turn Ratio: 450 to 1.

4. Average shear strength of individual spot welds: 1034 lb.

5. X-ray Results: All high-quality welds, free from cracks, porosity and expulsion.

D—TEST RESULTS

1. Fatigue Tests Under Cyclic Pull-Pull Loads with Five Various Types of Multiple Joints in the As-Received and Hydrostatically Treated Condition (Figs. 2 to 6)

These tests have been carried out on a Krouse Direct Repeated stress twin-testing machine with a capacity of 5000 lb. (Number of cycles: 1500 per min.) All specimens were stressed so that the minimum load was about 20% of the maximum tension load. This machine stops automatically if the load decreases slightly, due to a fatigue crack developing in the joints.

In the as-received condition, as well as after hydrostatic treatment, all five types of multiple joints have been investigated under cyclic pull-pull loads up to fracture. At a fatigue limit, as agreed at a maximum of 10,000,000 cycles, no visible cracks near the welds is to be found. The time necessary to reach 10,000,000 cycles on this machine is about a week. A few tests have been run up to 15,000,000 and 20,000,000 cycles. Test results, showing a discrepancy on the *S–N* diagram, were checked by other specimens and in some cases the average of two readings has been taken as final test results.

As represented in Fig. 2, joints with *two-spot* arrangements in *horizontal* position show in the as-received condition a fatigue limit of about 400 lb. At this load, the joint supported over 10,000,000 cycles without failure. Hydrostatically treated specimens of this type, as described in a previous work[1] and indicated in this figure by square signs, supported over 10,000,000 cycles without cracking at a repeated load of 650 lb. The *S–N* diagram is in this case somewhat flatter if compared to untreated joints.

Similar results have been found for the joint with a *two-spot* arrangement, one spot above the other, as this is represented in Fig. 3. For untreated specimens, a fatigue limit at over 10,000,000 cycles has been found to be about 400 lb, which is more or less the same value as for two spots placed in horizontal position. Hydrostatically treated specimens of this type will stand about 700 lb, a somewhat higher cyclic load without failure than as-received double spots in horizontal position. The *S–N* diagram of treated specimens is also slightly flatter compared to untreated joints where the number of cycles increases only slowly with decreasing repeated loads.

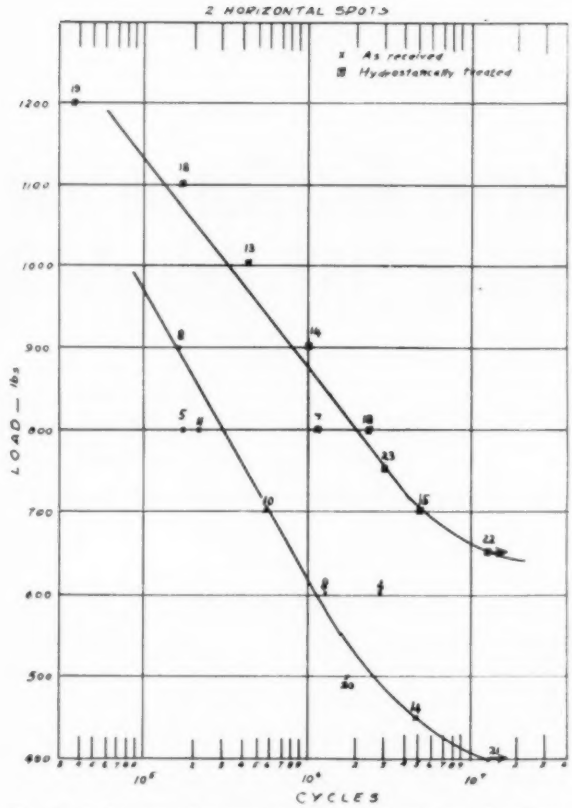

Fig. 2 S-N curves for two spot joints, horizontal pattern, for hydrostatically treated and as-received specimens

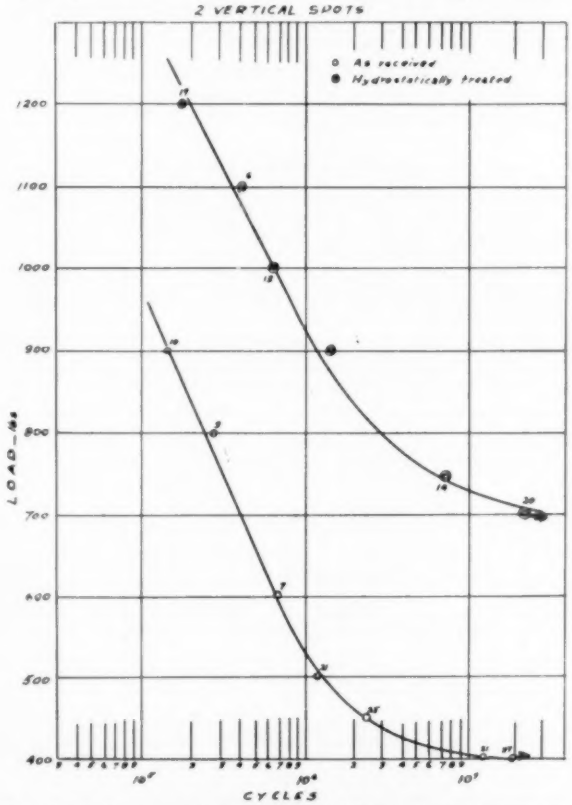

Fig. 3 S-N curves for two spot joints, vertical pattern, for hydrostatically treated and as-received specimens

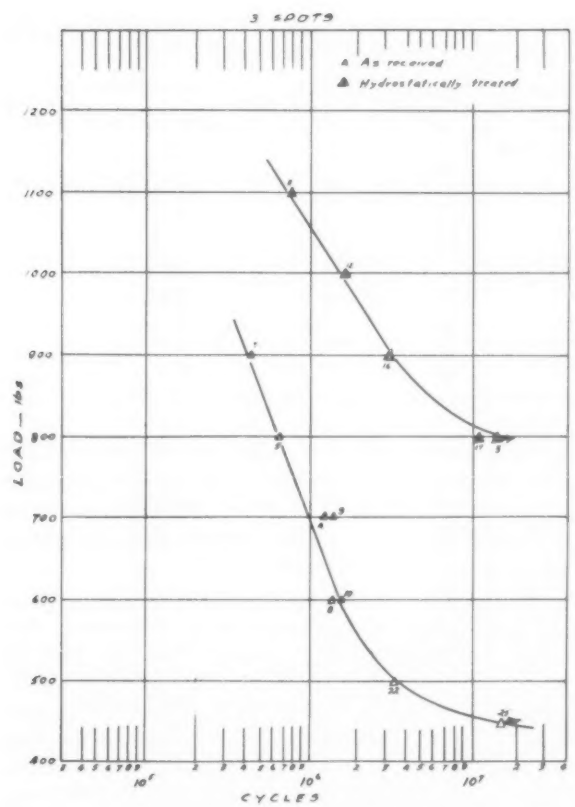

Fig. 4 S-N curves for three spot joints, for hydrostatically treated and as-received specimens

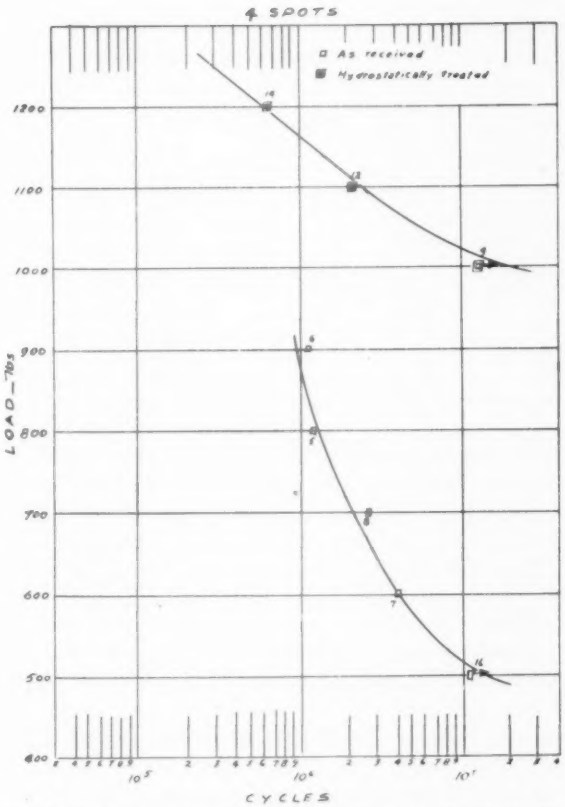

Fig. 5 S-N curves four four spot joints, for hydrostatically treated and as-received specimens

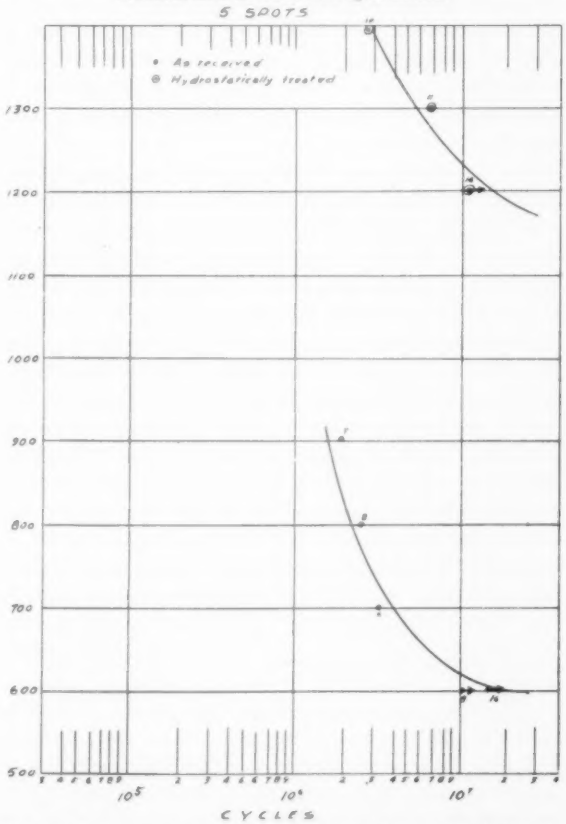

Fig. 6 S-N curves for five spot joints for hydrostatically treated and as-received specimens

The fatigue results of *three-spot* arrangements, as represented in Fig. 4, show for untreated joints a similar characteristic as for the *two-spot* arrangements. The number of cycles is, for all loads, higher than for the preceding joints and the fatigue limit has been reached at about 450 lb; this specimen supported about 15,000,000 cycles without failure. After hydrostatic treatment, the repeated loads for a similar number of cycles were very much higher. For these joints, the endurance limit has been found to be in the order of 800 lb.

As represented in Fig. 5, *quadruple spot* joints also indicate in the as-received as well as in the treated condition very interesting results. The fatigue limit of about 500 lb for untreated specimens can be increased by hydrostatic compression to about 100%, so that a load of 1000 lb repeated more than 13,000,000 times has been supported without failure.

The fatigue results with *five spots* are represented in Fig. 6. They indicate a similar improvement by hydrostatic treatment, compared to joints in the as-received condition. At the fatigue limit of over 10,000,000 cycles, untreated joints supported about 600 lb, while treated joints could be loaded under the same number of cycles to about double the amount, that is up to 1200 lb without showing any fatigue crack.

It can be noted from Table 1 that the fatigue resistance per spot is decreasing from 200 lb for one and two

Table 1—Tensile Strength and Fatigue Load in Relation to Spot Arrangement

No.	No. of spots	Maximum tensile load, lb	Actual fatigue limit, lb	Fatigue limit per spot, lb	Fatigue ratio: Actual fatigue load / Maximum tensile load, %
			As-received specimens		
1	2 horiz.	2190	400	200	18.2
2	2 vert.	2420	400	200	16.5
3	3	3310	450	150	13.6
4	4	4390	500	125	11.4
5	5	5380	600	120	11.1
			Hydrostatically treated specimens		
6	2 horiz.	2138	700	350	32.8
7	2 vert.	2338	650	325	28.0
8	3	3420	800	270	23.4
9	4	4060	1000	250	24.6
10	5	5270	1200	240	22.7

spots regularly to 120 lb only for five-spot arrangements. This means, in other words, that the fatigue resistance per spot for joints with one to five spots is decreasing with an increasing number of spots per joint. This is also true for hydrostatically treated specimens decreasing from 325 lb per spot for double-spot welds to 240 lb per spot for the joints with five spots.

Based on these fatigue test results, it can be said that the hydrostatic treatment of multiple spot-welded joints has a marked influence on their fatigue limit. As already indicated, for single spot welds, by a 150,000 psi hydrostatic compression of multiple aluminum alloy joints, an improvement of about 80 to 100% of their endurance limit is obtained. Furthermore, it seems possible to reach still higher fatigue loads by studying carefully the optimum pressure applied during the hydrostatic treatment, as well as the size and shape of the die to be used to produce the local compression of the individual spots, once the welding process is completed.

These fatigue tests have been conducted under the usually accepted standard methods by loading one specimen with one definite load only, the load being repeated a number of cycles up to fracture of the specimen. This means that for each point plotted in the *S–N* curve one specimen has been used.

In order to find out the influence of gradually loading the specimens, that is, from a minimum load applied a certain number of cycles under usual loading, and then higher the fatigue load, a series of tests have been carried out with specimens in the as-received condition. Welded specimens having two spots in horizontal and vertical positions as well as triple, quadruple and quintuple spot welds have been used for these tests The load has been increased for all spot arrangements after every 8 to 10 million cycles. Moreover for triple and quadruple joints a load increase took place after every five million cycles.

By the results represented in Table 2, compared to the fatigue limit of specimens in the as-received condition at 10,000,000 cycles under a constant load, as shown in Figs. (2–6), it can be seen that by a gradual increase of the fatigue load of the spot welds only about a 10% higher load can be found as fatigue limit. This method which is known as the "training" of specimens under fatigue is fairly slow, the number of cycles being extremely high to obtain the desired fatigue limit. For this test series alone, over 145,000,000 cycles at various loads were necessary. This means that by using a fatigue machine at the rate of 1500 cpm, a period of about 70 days of 24 hr or 2 1/2 to 3 months of uninterrupted work of the machine of a 6-day week has been necessary to carry out this part of the investigation alone.

2. *The Fatigue Limit of Multiple Spot Welds in Relation to Their Ultimate Tensile Load*

Copies of original load-deformation diagrams of untreated and hydrostatically treated specimens, as recorded on a Universal 60,000-lb Baldwin machine up to the rupture load are represented in Fig. 7 for all multiple spot arrangements, as well as for a single-spot specimen. From these test results, it can be seen that a hydrostatic compression of the welds has no marked

Table 2—Fatigue Limit Reached After Progressive Loading

	Double horizontal	Double vertical	Triple		Quadruple		Quintuple
Fatigue limit by standard method	400	400	450		500		600
	8–10 M cyc.	8–10 M cyc.	8–10 M	5 M	8–10 M	5 M	8–10 M cyc.
Progressive increase of fatigue load by "training"	400	400	400	400	400		400
	450	450	450	450	450		450
			500	500	500	500	500
					550	550	550
					600		
Total number of cycles in millions	9.988	12.7	24.5	12.3	43.5	8.1	35.5
GRAND TOTAL OF CYCLES 146.6 M.					M = Million cycles		

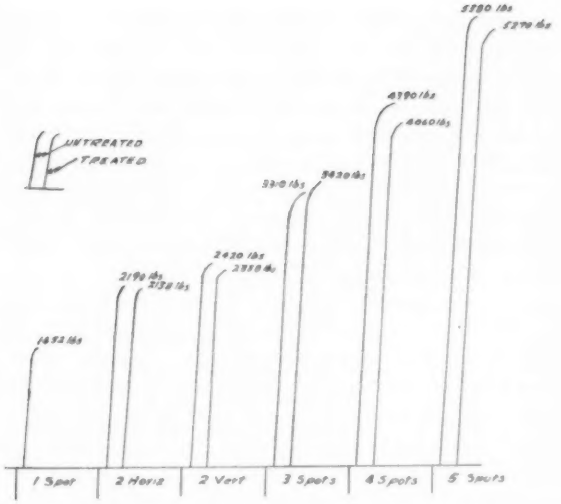

Fig. 7 Automatic recording to rupture for untreated and treated specimens

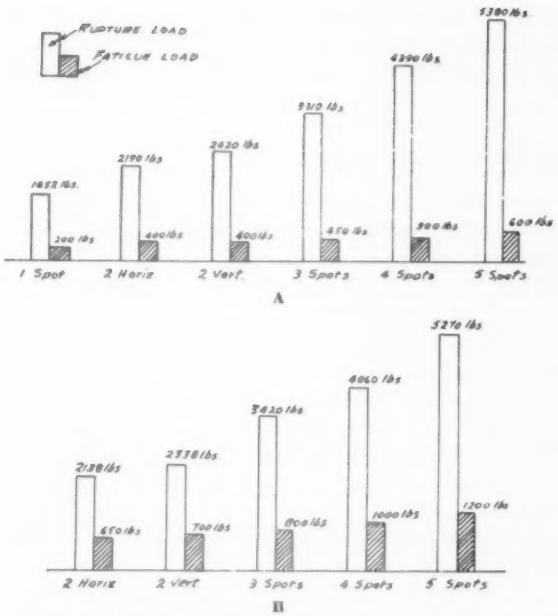

Fig. 8 Maximum load for rupture in relation to fatigue load at 10,000,000 cycles. (A) Untreated specimens. (B) Hydrostatically treated specimens

influence on the stress-strain diagram of these joints nor on the ultimate breaking loads. This is also visible in Fig. 8 where these results are represented statistically in bar graphs together with those of the fatigue limit of the joints in the as-received condition and after hydrostatic treatment. The rupture load increases with the number of spots under shearing. Each additional spot increases the ultimate load roughly of about 1000 to 1100 lb. In Table 1, the fatigue limit is expressed in percentage of the ultimate load in the as-received and hydrostatically treated conditions for one- to five-spot arrangements. The fatigue limit of 400 lb for untreated double-spot welded specimens increases to about 600 lb for five-spot welds which is in percentage of the ultimate shear load only 18% compared to 11%. A similar behavior has been found with hydrostatically treated specimens. Their endurance limit increases from 650 and 700 lb for the two-spot arrangements to 1200 lb for the five-spot welded joints, while the percentage of the ultimate load decreases from about 32 to 22%.

In the as-received condition, the fatigue limit is about $^1/_6$ to $^1/_9$ of the ultimate shear load compared to about $^1/_3$ to $^1/_{4.5}$ for hydrostatically treated specimens. It can be said that a fatigue limit of roughly 23 to 32% of the ultimate shearing load, as this is the case for these hydrostatically treated welds, is not too bad and stands comparison with structural materials such as mild steel medium and high-carbon steels as well as aluminum and copper alloys with roughly a fatigue limit of about 35 to 58% of their ultimate rupture load in tension (see Seely, *Resistance of Materials*, 3rd ed., p. 293).

Consequently these joints have, after hydrostatic treatment, a fatigue limit which is in an acceptable proportion to the ultimate rupture load, approaching that of other materials used in modern structures. In addition, there is some hope to still improve further these joints to a certain degree by a final adjustment of the hydrostatic treatment of these welds.

Based on results of fatigue tests carried out under repeated pull-pull loads, it can be said that:

1. The hydrostatic treatment of multiple spot-welded joints has, as for single spot welds, a marked influence on their fatigue limit. By a hydrostatic compression of multiple joints of about 150,000 psi in the area of the spot, an improvement of about 80 to 100% of their endurance limit has been obtained as this is illustrated in Figs. (2–6). Still better results should be possible by a careful study of the optimum hydrostatic pressure application and the best possible shape of the die in form of a very resistant steel piston to produce the local compression of the individual spot applied after the welding process is completed.

2. After hydrostatic treatment, these joints have a fatigue limit which is in an acceptable relation to the ultimate rupture load under fatigue, approaching that of other structural materials.

3. The stress distribution around the spot as investigated in detail has been found to be of a complex nature taking place in a very reduced and critical zone at the interface of the weld. The intensity of the stresses is decreasing in this zone from the inside surface of the joint in all three directions, that is, sidewise of the horizontal axis of the joint, toward the interior of the sheet up to the neutral axis and in axial direction away from the edge of the spot. In fact, a stress concentration of paramount intensity takes place in this very localized zone situated at the interface of the joint and immediately above the welded material in the heat-affected zone of the rigid spot. It is understandable that under repeated loads a crack develops in crystals of unfavorable orientation giving an explanation for the surprisingly low endurance limit of spot-welded joints of all kinds of material.

E—MEASUREMENTS WITH HIGH-PRECISION HUGGENBERGER TENSOMETERS IN CRITICAL ZONES OF MULTIPLE SPOT-WELDED JOINTS

Summary of Findings

In continuation of earlier work carried out on single spot-welded samples, in this investigation are described results of tests made with multiple spot-welded Alclad aluminum 24ST joints of 0.064-in. sheet thickness. By previous work, it has been shown that the main stresses and flow of material of spot-welded overlapped joints, during load transmission from one leg of the weld to the other, take place at the interface of the joint in the immediate vicinity of the spot. Extensive measurements with high-precision tensometers, adjusted in the critical zones of these multiple specimens, where the total and permanent microdeformations are developed under static loads, were made. They have led to the following findings.

1. The reliability of the measuring instruments has been proved by adjusting four tensometers of the same type in the length axis of a plain aluminum alloy specimen. All instruments showed, under load increments of 100 lb up to stresses of about 15,400 psi in these sheets, complete proportionality and close results regarding the total microdeformation in inch per inch; no permanent deformation could be recorded up to these tension stresses and a modulus of elasticity of the sheet of a value of about 10,000,000 psi has been found; this is in good accordance with the generally accepted moduli for aluminum alloys. By this result, it has been proved that the indication of all four instruments used are quite reliable and measurements, having an accuracy close to a ten thousandth of an inch, have been obtained.

2. Checking the axiality of the applied loads and the stress distribution over the cross section of the specimens, by the use of the same four tensometers, it has been found that the stresses are distributed quite satisfactorily over the cross section of the sample, as measured in two different sections. Special grips with spherical universal joints served for a more axial load application from the machine to the specimens tested. These results as well as those of the calculated modulus of elasticity of aluminum sheets check with the preceding ones and prove also the reliability of the four tensometers used for these minute measurements.

3. By similar tests to find out the accuracy of these instruments, the elastic and permanent deformations in an aluminum sheet around a hole of $^1/_4$ in. diam have been measured under elastic and plastic stresses. According to the results obtained, it becomes evident that the sensitivity of these instruments is very great; they are completely reliable regarding these indications about elastic and plastic microstrains and any doubt about their accuracy or the results of the measurements obtained by testing this kind of welded joints has to be discarded.

4. Based on these preliminary results, microstrain measurements at the interface and in the axis of multiple spot-welded sheets in the as-received condition have been made. It has been found that the indications of the instruments are very consistent; on double spot welds in vertical as well as horizontal arrangements, the microstrains are, under a load of 1200 lb, relatively appreciable, showing 0.004–0.005 in./in., while permanent plastic deformations have been found to be at this load about 25% of these values.

5. Triple spot-welded joints show, at the same load of 1200 lb, total microdeformations of about half of those of the double-spot arrangement; no great differences between the total microdeformation of the upper single spot (0.003 in./in.) and the lower two spots (0.0025 in./in.) of this arrangement has been found.

6. For quadruple and quintuple spot arrangements, somewhat lower total microdeformations have been recorded for the outside spots, while they are practically inexistent in the central spot of the five-spot arrangements. With the number of spots, the moduli of these joints are increasing regularly from the lowest for double joints up to the highest for quintuple joints.

7. After hydrostatic treatment of the joints, the results of the strain measurements at the interface in the axis of multiple spot-welded joints are very close to those of specimens in the as-received condition; they represent a confirmation for the results obtained with untreated multiple joints. It seems, however, as if the hydrostatically treated specimens show permanent deformations at somewhat lower loads than untreated welds.

8. Results of strain measurements in various zones around double and triple spot welds obtained at various distance points from the center of the spot do not vary very much with increasing distances from the spot. This indicates that these strains measured at the interface are prevailingly due to a bending effect which in its initial state is greatly elastic and is not due to local flow of the sheet in the adjoining zone of the spot. This mainly elastic bending of the joint takes place around the horizontal axis of a single spot for instance and over the whole width of the joint. The sheet under tension suffers in this case a double bending movement taking place around the horizontal and vertical axes of the spot, forming a kind of depression at the center of the joint.

9. Under prevention of the bending effect, by using a rigid steel sheath over the joint, about 30 to 40% lower total microdeformations have been recorded according to the distance of the measured zone from the spot. These tests show also that very pronounced bending effects of a rather complex nature develop in the welded joints under tension.

10. By microdeformations, as measured on the outside surfaces of double-welded specimens, in comparison to those measured at the interface, no total deformation whatsoever could be recorded between and above the spots; on the contrary, the tensometers have a tendency to show negative strains, indicating com-

pression stresses in these zones of the joints, put under tension loads.

11. These tests, measuring the microdeformations in 10,000 of an inch per inch at the interface of the spot weld over a rather short distance and in an inaccessible zone where the main stresses are concentrated, permit a first hand investigation of the intriguing low fatigue resistance of the joint, the possibility to build up a clearer picture of what is going on in the rather complicated transmission process of stresses introduced from the sheets to the spots of welded joints put under low static and repeated loads.

12. The angle of deflection of the spots in their horizontal axis has been measured during loading of double and triple spot-welded joints; it is rapidly increasing under increasing loads and shows already under fairly low external loads of about 200 lb a small permanent deflection of a few minutes in double spot-welded joints; the same amount of permanent deflection of triple welded joints has been found at much higher loads. Also the total deflection of the weld with three spots takes place at loads which are about 40 to 50% higher than those of the double welded joints.

13. The actual bending of double and triple welded joints, due to stressing, is of interest to study in order to give a clearer picture of the rather involved changes in flatness of the sheets around the spots and to find out the kind and degree of concavity building up around the spots in multiple welds.

14. Hardness survey over the cross section of untreated and hydrostatically treated welds show no very characteristic differences either between the unwelded sheets and the welded spot itself (about 30 to 40 Vhn) and untreated and hydrostatically treated specimens. In both cases, an average difference of about the same amount has been found. Furthermore, the compressed spot seems to have a somewhat reduced zone of minimum hardness compared to untreated welds.

Detailed results of these tests are available in form of graphs in a report[7] already submitted to the Welding Research Council, the above being an excerpt from that report.

F—SOME THEORETICAL CONSIDERATIONS ABOUT THE STRESS DISTRIBUTION AROUND THE SPOTS

Considering the results recorded by measurements made at the interface and in the longitudinal axis of the spots in multiple joints, we can make the following observations about the stress distribution in the critical zone around the spots. Assuming that the spot itself, representing a more or less rigid block *b* of cast material due to the high welding temperatures reached during the welding process, does not undergo any major plastic deformation, the elastic and microplastic deformations recorded by the Huggenberger extensometers at 1/4 in. distance from the center of the spots are concentrated at the interface in the critical heat-affected zone *a-a'* as a very pronounced bending of the

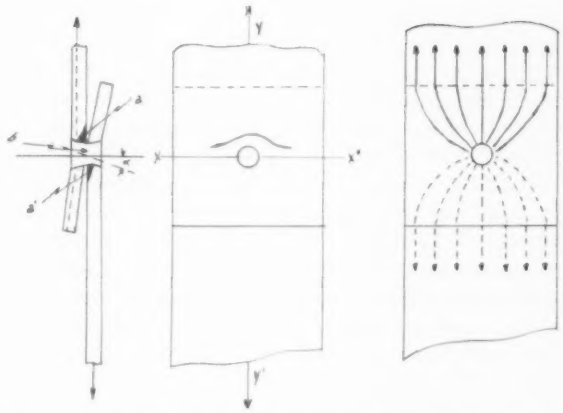

Fig. 9 Probable stress distribution around a one spot joint

overlapped sheets takes place under increasing loads (Fig. 9). Furthermore, these microdeformations are located over a fairly small volume of the sheet metal reaching from the interface toward the neutral axis *x-x'*, of the sheet under tension. The intensity of the stresses in this zone is necessarily decreasing rapidly from point *a*, Fig. 9, at the intersection of the interface with the solid spot in all three directions, toward the neutral axis *x-x'*, away from the spot in vertical direction, as shown by experimental results, and finally also toward both sides of the longitudinal axis *y-y'* of the joint, as this has been found by direct measurement as well as by the shape of the fatigue cracks developing at the interface of the weld at a very short distance from the solid block of the spot itself. This means that a triple stress concentration takes place on the tension side of the sheet in this most vulnerable zone located very close to the spot. Furthermore, as was shown by the angle of deflection of the spot itself under increasing loads, as well as by the measurements of the gap between the overlapped sheets, having the tendency to bend simultaneously in two directions perpendicular to each other, biaxial stresses take place in this already highly stressed, very limited zone *a* at the interface of the weld. This means that at this point located at the inside surface of the sheet, a few crystals orientated in such a way that their endurance against repeated stresses is low will start to show fatigue cracks. The propagation of these cracks takes place in a matter of time due to their effect of notching at even lower loads than those initiating the cracks at the fatigue loads. In fact, the fatigue cracks which can be observed at the outside surface on overlapped multiple spot welds are already a further phase of the crack development starting at the interface. All fatigue cracks of this type begin to develop already at a much smaller number of cycles than those recorded by the pulsator at the fatigue limit. Cracks, as developed at the interface, are not visible at the beginning until they propagate under repeated loading through the whole thickness of the sheet, so that they become visible only at a later phase of the fatigue process. An improvement of the

fatigue resistance properties in this critical zone of the spot, obtained by the hydrostatic compression treatment of the joint, seems to be an explanation for the much higher endurance limit of these welds. On the other hand, a simple local cold compression, without prevention of the material to flow sidewise as done by the hydrostatic principle, does not produce the same effect. In this case, the material, if freely compressed under stresses of 150,000 to 200,000 psi, will have properties weakened by these stresses due to the fact that it is squeezed out from the spot in zones which remain unaffected during repeated loading of the joint. Furthermore, the cross section of the spot is markedly reduced and consequently less resistant to repeated loads. Under hydrostatic compression, however, of the abovementioned amount, practically no appreciable changes in the spots are visible and due to the only possible very small internal flow and rearrangement of the crystals in the material under these extremely high pressures, the fatigue limit is greatly improved. It seems as if the spot and its adjacent zones become denser by eliminating small internal voids and cracks in the cast and heat-affected material, so that by this very limited internal flow of the material, the mechanical properties regarding the endurance limit, as this could be shown for 24ST aluminum alloy sheets, are fundamentally changed; a spot-welded joint is produced which is remarkably improved in its endurance limit, so surprisingly low in untreated welds.

It may be assumed that due to the hydrostatic compression process, the weakest axis of the crystals being in a cast condition are orientated concentrically in a much more favorable way with regards to repeated fatigue stresses than in the untreated specimens. The final answer to this question can be given only after the crystal structure around the spots of hydrostatically treated specimens has been studied by X-ray diffraction methods in comparison with untreated as-received samples.

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N.B.: Nos. 8 and 9 are abstracted and will be published shortly.

Welding Research in the European Universities

by Prof. A. Portevin

THIS opportunity of addressing a few words to you is a great pleasure for me. My only regret is that I cannot be with you in person, for, as we all know, those who are united in the great task of teaching always derive a deep satisfaction from meeting and sharing their experiences.

In view of my inability to be among you, only the kindly insistance of our friends Messrs. Biers and Spraragen persuaded me to prepare these few words; and so through their interest, I speak to you as Founder-Vice-President of the International Institute of Welding. I was asked to talk about "Welding Research in the European Universities"—to me a discouraging subject because I know so well the extreme diversity of organization in the various European countries and indeed the different views among us even to the concept of the word "university." My first reaction, therefore, was entirely negative for fear of talking to you either too briefly or at too great length—in either case, hardly effectively. However, after reflection, I thought you might perhaps be interested in an over-all statement of the position and in the difficulties and hopes we have in Europe. This will explain why I find it impossible to discuss in detail the topic suggested to me.

One of the greatest difficulties in Europe is presented by our numerous national boundaries. The distance between Houston, Tex., where you met last June, and Cleveland, Ohio, where you are gathered today, is roughly equivalent to that between Copenhagen, Denmark, and Florence, Italy. (I purposely chose these two

(*Continued on page 111-s*)

Prof. A. Portevin is Founder-Vice-President of the International Institute of Welding and Member of the Institute of France.

Translated from French and read at University Research Conference, WRC, Cleveland, Ohio, Oct. 21, 1953.

Report on Brittle Fracture Studies

Causes of storage tank failures, remedial steps and preliminary results in developing a test to simulate conditions at the time of tank failure which may result in the use of better steel

by F. J. Feely, Jr., D. Hrtko, S. R. Kleppe and M. S. Northup

I. INTRODUCTION

THIS paper covers progress to date on brittle fracture studies being conducted in the Standard Oil Development Co., Esso Engineering Department Laboratories. These studies were undertaken to investigate the cause of failure of two large oil storage tanks in England in the spring of 1952. The object is to determine what can be done to insure against similar tank failures in the future.

The investigation has covered the broad field of possible causes of tank failures and definite steps have been taken by our company to improve the quality of welding through the use of radiographic examination. At the same time, a laboratory program was begun to determine whether the use of better steel was the ultimate solution to the brittle fracture problem.

From the beginning of the laboratory program, emphasis has been placed on developing a test to simulate conditions at the time of the tank failure. The paper outlines the steps taken in developing this test, and, in particular, studies of the effect of changing specimen size, geometry, notch acuity, impact, and other test variables. A comparison is made showing the close agreement between test results and actual conditions at the time of failure, using steel from the two tanks which failed in England. Finally, a correlation is made between the test results and fundamental physical properties of the materials tested.

II. SUMMARY

The Standard Oil Development Co. investigation of the brittle fracture in tank steel makes use of a test procedure which was originated in the company laboratory. This procedure was developed with a view to duplicating the conditions in a tank which fails in a brittle fashion. Certain features of other studies have helped in developing the test, but it is believed to be unique in most respects. The object of the test is to relate both stress and temperature to the propagation of brittle fractures.

The test developed utilizes notched tensile specimens varying from 6 to 40 in. wide and 3 to 16 ft long. The notch is an extremely fine brittle crack which is introduced at liquid nitrogen temperature prior to the test. Under constant stress and temperature conditions, a hardened steel wedge is driven into the notch using an impact gun. If the stress is below a certain critical value, the notch is only slightly extended and no failure occurs. If the stress is above this critical value, however, the specimen fails completely with a brittle fracture.

Using this type of test, approximately 120 specimens of steel plate have been tested thus far. Several different types of steel have been tested, with the majority of work being concentrated on a single large ASTM A-285 plate in order to investigate all test variables. The data obtained indicate that below a certain temperature called the SOD transition temperature, the brittle breaking stress is constant while above this temperature the brittle breaking stress increases markedly.

Considering the usual variation in physical properties found in testing steel, remarkable agreement exists between the brittle breaking stress of the Fawley steel as determined by the Esso Engineering test and the calculated stress in the tanks at the time of failure. The stress required for brittle failure to occur in the laboratory for steel from one tank was found to be between 12,000 and 14,000 psi at 40° F. Failure of the tank occurred at a calculated stress of 15,800 psi at 40° F. This is felt to be a good indication that the test is truly indicative of conditions in a tank at the time of failure.

One of the objectives of the laboratory program is to determine whether or not conventional ASTM A-7 tank steel should be replaced with a higher quality steel which is less subject to brittle fracture. Tests on American A-7 tank steels show a wide range of notch-resistant properties for this material. From a preliminary standpoint, results indicate that American Bureau of Shipping Class C steel corresponds to an A-7 plate which has high notch-resistant properties. English steel from the broken tanks at Fawley, on the

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Presented at Conference on Brittle Fracture Mechanics sponsored by Committee on Ship Structural Design at Massachusetts Institute of Technology, Oct. 15 and 16, 1953.

other hand, correspond to an A-7 plate which has low notch-resistant properties. Considerably more work is necessary, however, before relative quality can be established on a satisfactory statistical basis.

There appears to be a fairly good correlation between the transition temperature determined by the SOD test and that found with the conventional Charpy V-notch impact test. Preliminary data also indicate that a correlation may also exist between the brittle breaking stress plateau and the modulus of rupture at liquid nitrogen temperature.

III. DEVELOPMENT OF A TEST

Background

Early in the laboratory program an effort was made to determine what causes a brittle fracture to continue to propagate in some instances and stop in others. It is assumed that conditions which cause a brittle fracture to start initially are localized and are probably more severe than the average conditions. In the case of tank failures, there is evidence to indicate this is true. For example, on two occasions, short brittle cracks have occurred in the same tanks which later failed completely under more severe stress conditions.

A review of the literature on brittle fracture studied prior to 1952 indicates that most of the emphasis was placed on determining the temperature where a given steel is subject to brittle fracture, using a number of different tests to indicate transition temperature range and correlating the results with actual failure experience. Notched tensile tests indicate brittle failures occur when the stress is in the range of yield stress or higher. It seems, therefore, that such tests are indicative only of conditions that lead to the start of a brittle fracture and do not shed light on propagation.

It was interesting to note, therefore, the work of Robertson in England who studied the effect of stress on the propogation of a brittle crack in specimens with a superimposed temperature gradient. Particularly interesting was the fact that he was unable to get a brittle crack to propagate when the stress was below 10,000 psi. This raised the question of whether there is a minimum stress below which brittle cracks will not propagate. It was decided to investigate this question further and an effort was made to duplicate Robertson's work with certain modifications as described hereafter.

Robertson Test

At this point, it is perhaps desirable to review briefly the Robertson test to provide background for the deviations employed. As reported in the British publication *Engineering*, dated Oct. 5, 1951, Robertson utilized a specimen of the type shown in Fig. 1. This specimen contained a stress concentrator composed of a nub on the side of the plate with a 1-in. diam hole where liquid nitrogen was used as a coolant. Heat was applied on the opposite side of the plate to establish the desired

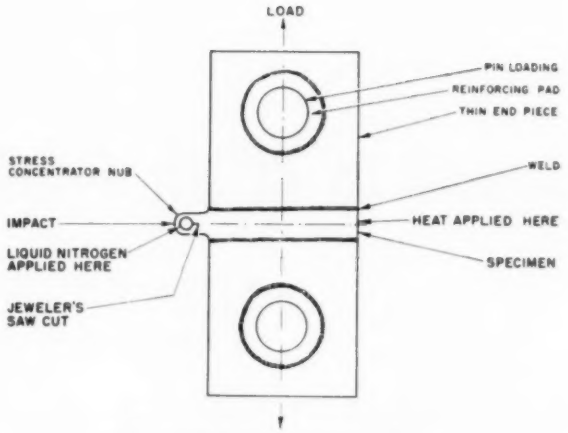


Fig. 1 Robertson type specimen

gradient across the specimen. On the inside of the hole, Robertson made a jeweler's saw cut. The plate was loaded through end connections which were of thinner plate so that they were stretched beyond the yield point during the test. This helped to correct any misalignment or bending conditions in the specimen. When the desired temperature gradient and stress were applied to the plate, an impacting device was directed at the outer surface of the stress concentrator nub. This resulted in a brittle crack starting at the jeweler's saw cut and propagating across the plate. The length of the crack thus produced depended upon the temperature gradient and the average stress level. Robertson determined the temperature at the end of the brittle crack by measuring the position of the tip of the thumbnail at the end of the brittle crack with respect to the temperature gradient on the specimen. He related this temperature to the stress in the specimen. Using this test, he found that different steels exhibited wide variations in properties. It was felt that perhaps the most significant finding was that below a stress of 10,000 psi Robertson could not get the brittle crack to propagate.

Several questions come to mind in considering this test, and its interpretation. Briefly, these are:

1. Was it possible to get uniform stress distribution with the specimen employed, particularly with a temperature gradient present?
2. Was the stress measured prior to impact significant and how was it related to the stress at the time the crack was arrested?
3. Were the results affected by the use of impact to start the crack?
4. Were the results affected by the size or geometry of the specimens employed?
5. Was the tip of the thumbnail the significant point from which to measure temperature?

Modified Robertson Test

The modified Robertson test which was run in the SOD laboratory employed a specimen as shown in

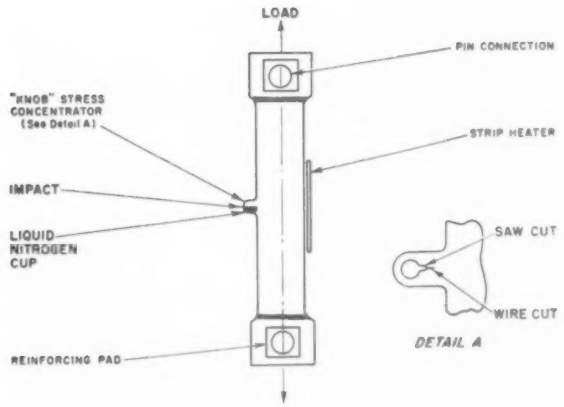


Fig. 2 Temperature gradient specimen

Fig. 2. A stress concentrator of the same design as Robertson's was used. In place of the plastic end connections used by Robertson, a longer specimen was substituted since it was felt that the transient stress from the impact would not be reflected back to disturb the stress distribution until the crack was well under way. It was decided to use strain gages instead of the extensometers used by Robertson for measuring strain. In view of the temperature gradient, it was necessary to do considerable experimental work on temperature compensation on strain gage readings. The stress gradient across the plate is shown on Fig. 3. It can be seen that the tensile stress in the direction of loading dropped off considerably near the notch due to the reinforcing effect of the stress concentrator nub. Also, it can be seen that a compressive stress in the transverse direction existed in the vicinity of the notch.

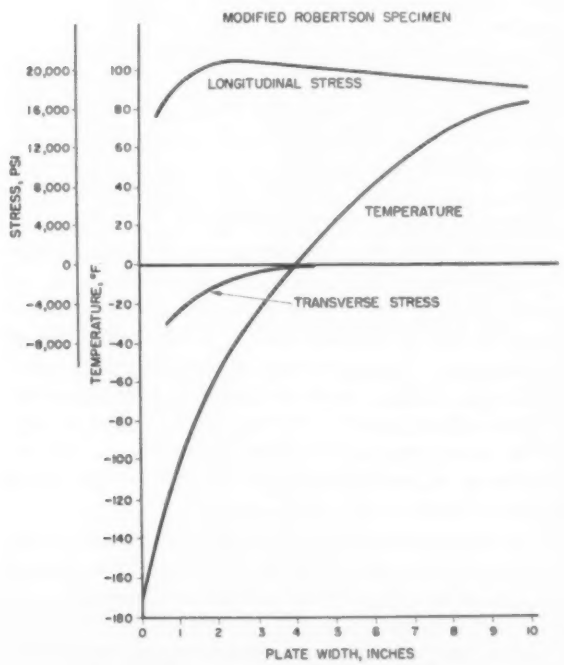


Fig. 3 Stress and temperature gradient

Five specimens were tested using this type test. All were made from a single ASTM A-285 rimmed steel plate from Lukens. It was found that the brittle crack started by impact would not propagate farther at an average stress of 15,000 psi than it would at no stress. At 20,000 psi average stress, the brittle crack traveled completely across most of the specimens due to the fact that the need for as high a temperature as was required to arrest the crack was not anticipated. The crack was finally stopped by increasing the temperature on the far side of the plate to approximately 140° F. With an average stress of 20,000 psi, the crack propagated across the plate and stopped at a point where the temperature was at 120° F. At this stage of the program, an evaluation of the modified Robertson tests was made and it was concluded that:

1. Poor stress distribution existed, with the axial tension low near the notch. An appreciable transverse compressive stress was also present. Both of these appeared to retard the start of a brittle crack and hinder propagation in the early stages.

2. There was an indication of a shifting stress pattern and it was thought that the difficulty encountered in stopping the crack might be related to this stress realignment.

3. The combined effects of items 1 and 2 raised a serious question as to the significance of any relationship between average stress prior to impact and the temperature where the crack stopped.

4. There was, however, a definite indication of a minimum stress below which brittle fractures would not propagate.

Stress Gradient Test

In view of the difficulties encountered in the modified Robertson work, it was decided to see if a crack could be stopped by having it run from a zone of higher stress into one of lower stress at constant temperature. It was reasoned that such a test might indicate the extent to which stresses shift as a crack propagates. For this test, an entirely new type of specimen was employed as shown in Fig. 4. This specimen was loaded eccentrically and contained a notch on one side. The

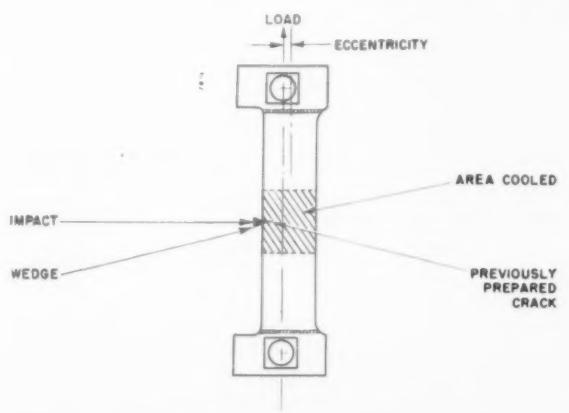


Fig. 4 Stress gradient specimen

notch was a brittle crack previously introduced into the plate at dry ice temperatures. The proportions of the specimen were such that the stress gradient existed across the plate. When this specimen was loaded in the machine to the point where the nominal tensile stress at the notch was approximately 20,000 psi, a compressive stress of 2000 psi existed on the opposite side. The temperature of the specimen was reduced to 0° F by circulating a cool nitrogen stream inside an insulating box. With the specimen at the desired stress and temperature, a hardened steel wedge was driven into the notch using an impact device. With a tensile stress on the leading edge of 15,000 psi, no break occurred; however, with the stress increased to 20,000 psi, complete failure occurred. The fact that complete failure occurred means that the crack either progressed through a compression zone, which seems highly unlikely, or that the stress pattern shifted so that tension was always present. With crack velocity being in the order of one-third the velocity of elastic strain waves in steel, such a shift in stress pattern might have been expected. This experiment, however, indicated that a shift definitely did occur and that it would be extremely difficult to predict the stress existing at the time a crack was arrested with the Robertson type test or any other test involving a running crack.

With this background, it was decided that a test of the "go, no-go" type at uniform stress and temperature was the most desirable from the standpoint of interpreting the results, and steps were taken to develop such a test.

SOD Test

The test which was used in our studies employs a specimen of the type shown in Fig. 5. This specimen contains a notch composed of a brittle crack on one edge and a saw cut of equal depth directly opposite. The brittle crack is introduced at liquid nitrogen temperatures. The exact technique used in preparing the specimen is as follows.

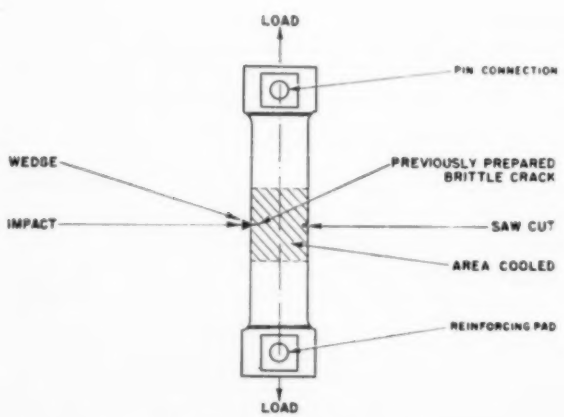


Fig. 5 Typical test setup

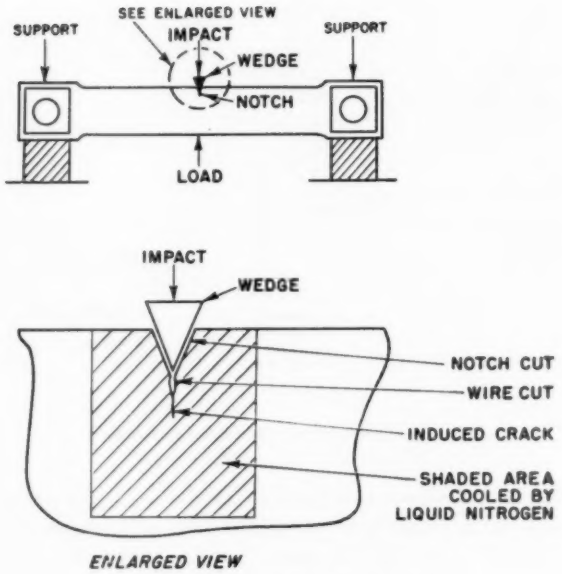


Fig. 6 Preparation of specimens

Steel which is to be tested is fabricated into a specimen which consists of a slab of the material with the necessary end connections for use in an ordinary tensile testing machine. A typical test piece is shown on Fig. 6, together with the method which is employed in preparing the specimen. A saw cut followed by a subsequent wire cut using a fine wire and grinding compound is made at the middle of the plate on one side. The specimen is then loaded as a simple beam to create a tensile stress in the outer fiber at the cut. The area in the vicinity of the cut is then cooled by means of liquid nitrogen. When the area is at about the temperature of liquid nitrogen, a wedge is driven into the saw cut by impact from a small slug shot at high velocity from a tool commercially available. This induces a fine crack at the base of the cut which is believed to be as severe a stress concentrator as any encountered from welding defects or other causes. A saw cut of the same depth as the crack is made on the opposite side of the specimen to improve stress distribution.

The test specimen is placed in a tensile testing machine and loaded axially through pin connections, as shown in Fig. 5. An insulated box is placed around the central portion of the plate and a cooling system placed in operation. Low temperatures are obtained by the use of dry nitrogen which is cooled in coils immersed in liquid nitrogen and is injected into the box in controlled quantities on both sides of the plate. The arrangement of equipment used in the laboratory is shown in Fig. 7.

Thermocouple readings taken during the test period permit accurate control of plate temperature. When the desired temperature is reached, a predetermined tensile load is applied to the specimen. At this point, an impact device is used to drive a hardened steel wedge into the previously prepared notch. The wedge is

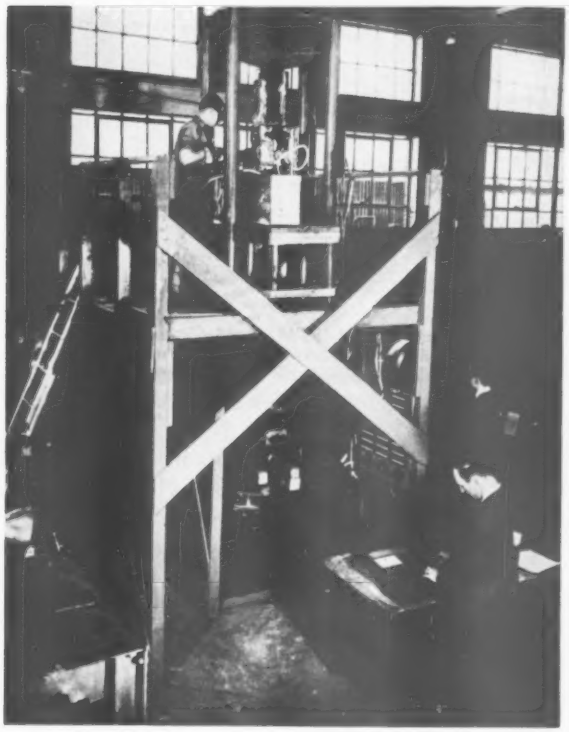


Figure 7

driven by the impact from a small slug shot at high velocity from the tool.

As complete brittle failure occurs, the material is considered to be subject to brittle fracture at the prevailing conditions. If failure does not occur, the tensile load is increased and the plate is subjected to impact at succeedingly higher stress levels until brittle fracture occurs. If the temperature is below a certain critical value, identical results are obtained regardless of whether the specimen is subjected to a number of impacts at progressively higher stresses until the brittle strength is reached or whether this final stress is applied at the first impact. At higher temperatures, this situation does not exist and it is necessary to determine through the use of additional specimens from the same plate the lowest stress at which the material will fail on first application of impact.

IV. STUDY OF TEST VARIABLES

Using the SOD test, approximately 120 specimens have been tested to date. The major portion of these have been from a single Lukens rimmed steel plate of ASTM A-285 specification. The properties of this plate, henceforth called Plate A, are shown in Table 1.

The principal purpose of this phase of the program was to determine what test conditions should be employed to simulate conditions existing at the time of tank failure. Accordingly, the effect of each test variable on the brittle breaking stress was studied individually by holding all others constant. The following variables were studied in this manner:

SPECIFICATION ASTM A-285 GRADE C (RIMMED STEEL).

SOURCE : LUKENS

CHEMICAL ANALYSIS		PHYSICAL PROPERTIES	
CARBON	25	YIELD STRENGTH	38,300 PSI
MANGANESE	49	ULTIMATE STRENGTH	59,500 PSI
SILICON	–		
PHOSPHOROUS	016		
SULFUR	040		

IMPACT DATA

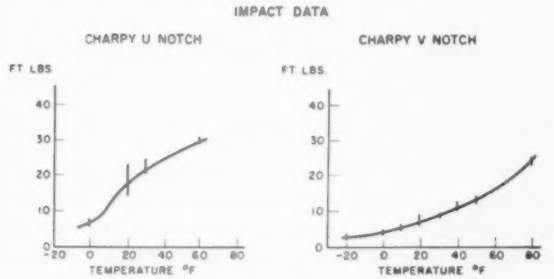


Table 1—Properties of Test Plate A

1. Temperature
2. Notch sharpness and length
3. Impact
4. Geometry and size
5. Material

It will be noted that plate thickness is not mentioned. Thus far, no work has been done on this variable. This work is, however, scheduled in the near future.

In general, it can be said that the results with the SOD test are quite reproducible. Deviations are usually less than 1000 psi where the brittle breaking stress is 10,000 to 15,000 psi. Using the "go, no-go" testing technique, it is almost always possible to narrow the range between failure and no failure to 1000 psi by testing two or possibly three specimens at a given condition.

Temperature vs. Stress

When all other test conditions are maintained constant, the relation between brittle breaking stress and temperature is shown in Fig. 8. The standardized conditions for all these tests are noted on the curve.

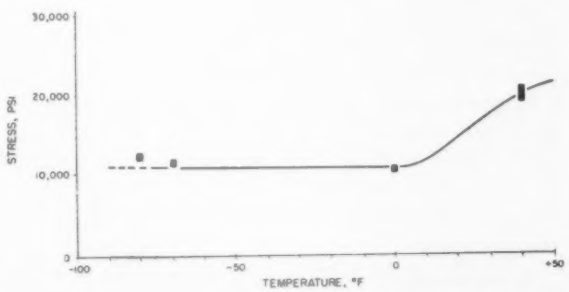


Fig. 8 Stress vs. temperature (ASTM A-285 GR.-C. Specimens: 6 ft by 10 in. by 1 in. Large gun, heavy charge)

Below 0° F, the brittle breaking stress is shown to be essentially constant. Above this temperature, the breaking stress increases markedly. This temperature is called the SOD transition temperature and it has been found to exist for all steels tested. It varies for different steels as will be discussed later. The exact shape of the curve between 0 and +40° F, while not definitely established by the data shown on Fig. 8, is known from the mass of additional data where some noncritical variables have been changed.

Notch Sharpness and Length

The effect of notch sharpness was studied over a considerable range and it was found that the brittle breaking stress is reduced as the notch is made sharper and sharper. The following tabulation presents the results of this work:

*Type notch**	*Radius at root, in.*	*Brittle breaking stress,† psi*
Saw cut	0.020	26,000–30,000
Wire cut	0.003	21,000–26,000
Dry ice crack	Unknown	16,000–17,000
Liquid nitrogen crack	Unknown	14,000–15,000

* All notches were essentially the same length, although this has been shown to have no effect.

† Tests were conducted on steel from Plate A at 0° F using specimens 6 ft long by 10 in. wide by 1 in. thick, and medium impact from the small gun.

The effect of notch length was also investigated. Liquid nitrogen cracks varying from $^3/_4$ to 2 in. in length were tested in pieces varying in width from 6 to 16 in., and no effect due to crack length was observed at any temperature. A few longer cracks were also tested and with these the breaking stresses was found to be higher. This is believed to be due to the fact that the wedge was not as effective with the longer crack. It would appear, therefore, that the crack length effect indicated by the Griffith theory does not apply to this test.

Impact

Considerable work was carried out to determine the effect of varying the impact energy used to start the brittle fracture. Figure 9 shows the brittle breaking stress as a function of impact energy with all other variables held constant. In obtaining data for this curve, two types of impact guns were used, each having a range of muzzle velocities. The slug shot from the small gun weighed 8.75 g and the slug from the large gun weighed 49.75 g. The velocities were determined through tests conducted at the Remington-Arms Laboratory. The energy in each case was calculated from the above data.

As the energy of the slug striking the wedge increases, the breaking stress decreases. This stress reaches a minimum of 10,000 to 11,000 psi for Plate A, at approxi-

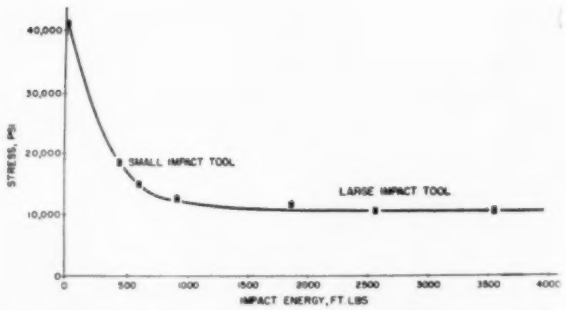


Fig. 9 Impact effect (ASTM A-285-C; 60-in. long, 10-in. wide, 1-in. thick specimens for temperatures below transition temperatures of the material)

mately 2500 ft-lb energy. Further increases in energy do not lower this stress.

The following is offered as one possible explanation for this behavior. The assumption is made that the running brittle crack is started by the combined effect of tensile stress due to load on the specimen and transient stress due to impact. At the lower impact levels, the transient stress available to initiate a running crack is insufficient and therefore additional stress in the form of stress due to load on the specimen is needed. Once the crack is started, there is enough energy in the stress field to sustain its continuation. As more and more impact is provided, however, less and less additional stress is needed from the specimen stress field to start the crack. Eventually a situation is reached in which no stress is required from the specimen stress field for crack initiation. In this case, the only stress needed in the test specimen is that required to propagate the crack. If the stress level in the specimen is lower than this minimum value, then the crack will not propagate.

Perhaps the feature of the SOD test which is most difficult for the average person to accept is the use of impact to start a brittle fracture. The question, "Where does impact come from in a tank failure?" has been raised by most of those to whom the test has been shown. It is believed that impact causes the wedge to spread the original brittle crack and this results in a very slight extension of the crack which usually is not measurable. At higher temperatures, when the stress is just below the failure stress, fairly large drops in load of the tensile testing machine have been noted, indicating appreciable extension of the notch. Therefore, it is believed that impact in itself is not important. It is merely a means of obtaining a moving crack in a specimen where a general stress level exists. As mentioned earlier, the lengths of specimens tested have been purposely kept long so that secondary effects from the transient stress due to impact will not affect the results.

An interesting experiment was conducted to attempt to demonstrate how impact might set off a tank failure. In this test a conventional specimen was prepared with the liquid nitrogen crack about $2^7/_8$ in. long. This

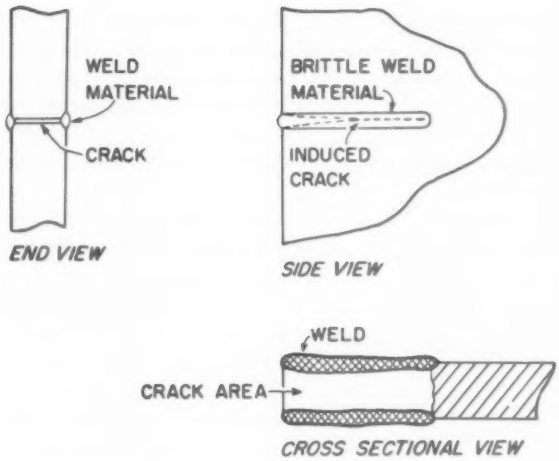


Fig. 10 Special test specimen

crack was then "buttered over" with a thin weld deposit on both sides of the plate. The resulting cross section is shown in Fig. 10. This specimen was cooled to −40° F and then gradually the load was increased until the brittle fracture occurred. The average stress at failure was 27,400 psi. This is 8000 psi below the yield point for this material at the temperature of the test. It is believed that if the amount of the weld deposit were less or the deposit less ductile, failure could occur at a lower stress, perhaps even approaching the stress found in the SOD test.

Geometry and Size

The effect of specimen geometry and size has been studied quite extensively below the SOD transition temperature and it has been found that variations in width, length, shape and size have no effect on the brittle breaking stress. Some work has been done at higher temperatures and still more is required to fully explain variations found. The present extent of knowledge is outlined as follows.

Width Effect. Specimens from Plate A of varying width have been tested at 0° F, the SOD transition temperature, and +40° F which is above this transition. The results are shown in Fig. 11. This work was carried out using the small impact gun with a medium charge and, under these conditions, it was found that at 0° F the brittle breaking stress was constant at 14,000–15,000 psi. At 40° F we found that an increase in width resulted in an increase in breaking stress. This effect has been checked for different length specimens and it has been found that a family of curves of varying slopes exist, two of which are also shown in Fig. 11. These curves all appear to converge at an imaginary point of 15,000 psi at 0 length.

No obvious explanation exists for this behavior, but it may well be due to the resistance offered by the specimen to the wedging action which was employed in starting the crack. Fortunately, this effect is not extreme.

Length Effect. Specimens of varying length were also tested under similar conditions and the results are shown on Fig. 11. As mentioned previously, no effect was found where the temperature was 0° F, which is the SOD transition temperature, for Plate A. At +40° F, the length affected the brittle breaking stress, being lower for longer specimens. It will be noted that as the specimen length increased the reduction in stress became progressively less and approached a constant value. Data on length effect, using specimens of two different widths (6 and 10 in.) and testing at +40° F are also shown in Fig. 12. As might be expected from data in Fig. 11, the wider plates had higher breaking stresses. It has been found, however, that if the length of the wider plate is increased sufficiently, this difference disappears.

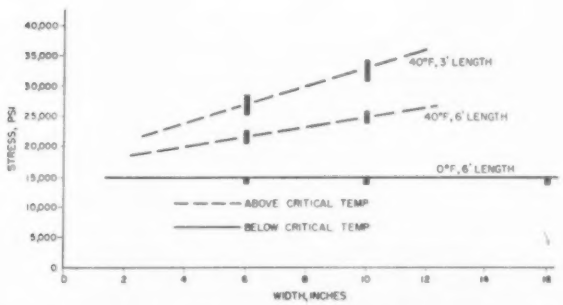


Fig. 11 Width effect (Plate A. ASTM A-285. Small gun, med. chrg. Liquid N_2 crack)

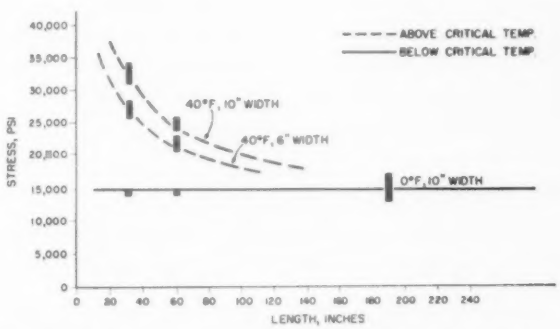


Fig. 12 Length effect (Plate A. ASTM-A-285. Small gun, med. chrg. Liquid N_2 crack)

Size Effect and Shape Effect. Using the data accumulated for the studies of width and length effects, it is possible to reach certain conclusions regarding size and shape effects.

It is apparent that at or below the SOD transition temperature no size or shape effect exists since changes in both width and length have no effect.

Above the SOD transition temperature, in the tests conducted on Plate A at +40° F, no appreciable effect of size was noted on two geometrically similar specimens.

It is planned to broaden the range of this work in the future with larger-scale tests at one of the universities.

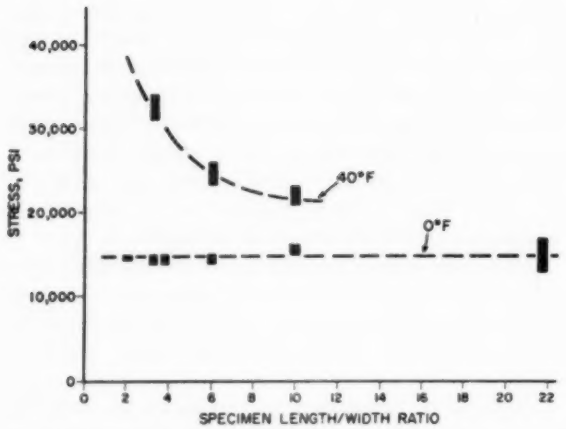


Fig. 13 Shape effect (ASTM A-285-GR.-C. 1-in. thick specimens. Small gun, med. chrg.)

On the basis that geometrically similar pieces of different size will give the same results, all the test data have been plotted on a single curve for shape effect. This is shown in Fig. 13. Here the brittle breaking stress vs. the length-to-width ratio (L/W) has been plotted. For tests at the SOD transition temperature (0° F), the stress is, of course, constant. At a higher temperature (+40° F), the brittle breaking stress falls off as the L/W ratio is increased and approaches a limiting stress asymptotically. This relationship provides a simple means of making adjustments to data obtained on one size specimen for comparison with another. It also indicates that it is desirable to use a specimen of L/W ratio of about 10 to insure that results close to the minimum brittle breaking stress are obtained when tests are run above the SOD transition temperature.

Miscellaneous Variables

Although all of the principal test variables have been covered, there are a few miscellaneous items which should be mentioned.

Stress distribution in the SOD test specimen has been investigated using strain gages and found to be fairly good. Stresses in the immediate vicinity of the notch and saw cut are undoubtedly high. However, they drop down to within 20% of the average stress a short distance away where the strain gages were located. Earlier it was mentioned that a saw cut equal in length to the crack is made on the opposite edge of the plate to insure good stress distribution. Actually, a few early tests were run without this saw cut and the results are identical with later tests employing the cut.

Mention was also made of the effect of repetitive impacts earlier in the paper. More details on this situation are outlined below:

1. *Below the SOD Transition Temperature:* Repetitive impacting has little effect. Tests have been made at four or five increasing stress levels and the results were identical with first or second impact tests. At stress levels just below the brittle breaking stress, say within 1000 psi, repetitive testing will result in failure. Some tests indicate an increase in brittle breaking stress when the number of impacts is excessive, say 5 to 10. This makes it desirable to make a rough survey for brittle breaking stress first and close in on the range in later tests.

2. *Above the SOD Transition Temperature:* If no failure occurs on the first impact when the temperature is above the SOD critical point, continued testing is usually of little significance. It appears that the first impact results in dulling of the notch through deformation at the root of the crack and the final breaking stress is usually considerably higher than would be found on first impact. This means that additional tests must be run to see what is the lowest stress at which failure occurs on the first impact.

Another interesting effect noted during the laboratory work was the wedge width. When a wedge narrower than the plate thickness was used, the brittle breaking stress was higher than when the wedge was equal to or greater than the thickness.

V. COMPARISON OF TEST RESULTS WITH FAILURES

The next important step in the laboratory program involved testing of steel from the English tanks which failed. The purpose of this work was to determine whether the SOD test would indicate the steel to be subject to brittle fracture at the conditions existing when the tanks ruptured.

Both of these tanks were built of steel purchased to British Specification BS 13. The failure in the first tank started at the junction of the first and second courses in a flaw at the root of the replacement weld made to fill up a weld probe. The failure in the second tank started in a poorly repaired crack at the tee junction between the vertical weld in the first course and the horizontal weld between the first and second courses. The failure started, however, in the second-course plate where the crack extended up into this plate.

The properties of the steel in the first two courses of both tanks are shown in Table 2. All plates fell within the rather broad specifications of BS 13 which is the British equivalent of ASTM A-7. Charpy V and U values for all plates are also plotted on this sheet.

At the time of both failures, the temperature was about +40° F. Both tanks were being water-tested when failure occurred and the calculated stresses at the time are shown below.

Tank failure	*Calculated stress, psi*
First	
1st course (top)	14,000
2nd course (bottom)	15,800
Second	
1st course (top)	12,500
2nd course (bottom)	14,200

Table 2—Properties of Fawley Tank Steel (Specification: BS-13, Semikilled. Source: Wessoe, Ltd.)

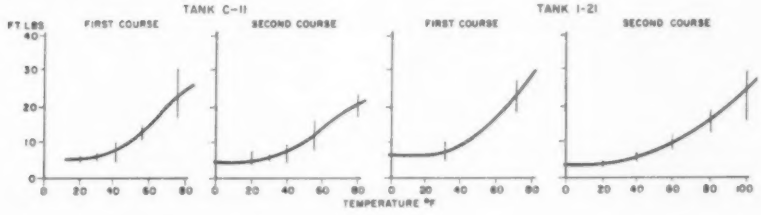
[illegible]

	TANK C-11		TANK I-21	
	FIRST COURSE	SECOND COURSE	FIRST COURSE	SECOND COURSE
CARBON	.165	.21	.245	.22
MANGANESE	.54	.56	.62	.54
PHOSPHORUS	.024	.024	.031	.031
SULFUR	.036	.041	.027	.03
SILICON	.015	.02	.04	.03

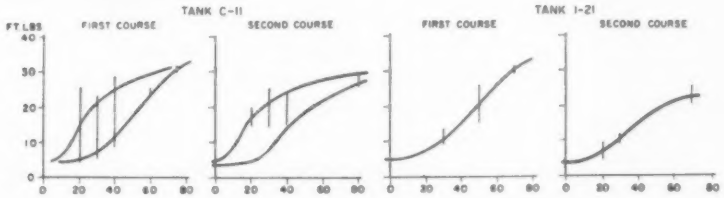
[illegible]

	TANK C-11		TANK I-21	
	FIRST COURSE	SECOND COURSE	FIRST COURSE	SECOND COURSE
YIELD STRENGTH, PSI	31,400	33,400	30,400	37,000
ULTIMATE STRENGTH, PSI	59,600	65,800	68,100	66,100
% ELONGATION	31	26.5	28	34
REDUCTION OF AREA	60.4	56.0	57	56

[illegible] CHARPY V NOTCH



[illegible] CHARPY U NOTCH



The SOD tests were made on plates from both the first and second courses of the first tank which failed, but only from the second course of the second tank. All specimens were 6 ft long by 10 in. wide. The large impacting gun was used and tests were made at varying temperatures from −150° F to +40° F. The results of these tests are shown on Fig. 14.

The data indicate that at +40° F the brittle breaking stress of the second course of the first tank to fail was 14,000–16,000 psi. The second-course plate for the other tank has an indicated brittle stress of 18,000–20,000 psi. These stresses compare fairly well with the calculated stresses as shown below:

	Calculated Stress, psi	*SOD tests*
First tank failure, 2nd course	15,800	14,000–16,000
Second tank failure, 2nd course	14,200	18,000–20,000

It is believed that the test results would show lower stresses for both plates if longer specimens were tested. This can be seen from Fig. 12, where length effect is illustrated above the SOD transition temperature. Unfortunately, the testing machine in the SOD laboratory cannot take larger specimens; however, it is planned to test a larger specimen in one of the universities. A further point in this regard must also be brought out, and that is that the laboratory tests were conducted on specimens having a length-width ratio of 6.0 while the tank proper has a ratio of 10.0. If a correction for this size effect is made, which has been determined by experiments to be 2000 to 3000 psi, the comparison of laboratory results and actual field experience for both tanks is then in even closer agreement. It must be pointed out, however, that any minor change in the notch-brittleness properties of a section of the steel, which would result in a slight shift of the curves, would also affect the correlation between laboratory and field results.

It is felt that satisfactory correspondence between the SOD test results and calculated stress conditions when the actual tank failures occurred has been obtained. These results indicate that the SOD test closely simulates conditions at time of failure and therefore provides a reliable means of evaluating steels with respect to their susceptibility to brittle fracture.

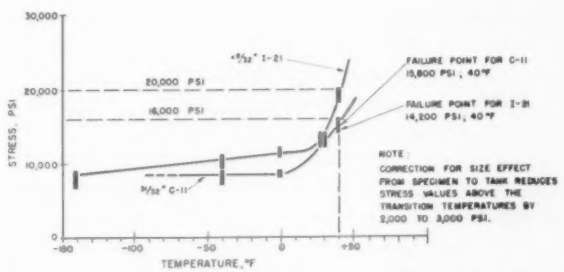


Fig. 14 Stress vs. temperature (Fawley Tank Steel. Specimens 6 ft by 10 in. by 1 in. Large gun. Second course plate)

VI. EVALUATION OF STEELS

The following different steels have been tested during the SOD tests:

ASTM A-285	1
ASTM A-7	1
BS 13	3 (tanks that failed)
ABS Class C	1
	6

Table 3—Properties of All Steels Tested

Steel plate	*A*	*B*	*C*	*D*	*E*	*F*
Source	Lukens (rimmed)	Inland steel	First Course, Fawley tank C-11	Second Course, Fawley Tank C-11	Second Course, Fawley Tank I-21	Bethlehem Steel
Specification	ASTM-A-285 GR C	ABS Class C	BS-13	BS-13	BS-13	ASTM A-7
Chemical properties:						
Carbon	0.25	0.20	0.165	0.21	0.22	0.20
Manganese	0.49	0.71	0.54	0.56	0.54	0.47
Phosphorus	0.016	0.014	0.024	0.024	0.031	0.008
Sulfur	0.040	0.030	0.036	0.041	0.03	0.033
Silicon	...	0.25	0.015	0.02	0.05	0.04
Physical properties:						
Yield strength	38,300	40,200	31,400	33,400	37,000	33,400
Ultimate strength	59,500	68,800	59,600	65,800	66,100	61,200
Elongation, %	...	25	31	26.5	34	...
Reduction of area	...	...	60.4	56	56	49.9
Impact data:						
U-Notch	*Temp. Ft-lb*	*Temp. Ft-lb*	*Temp. Ft-lb*	*Temp. Ft-lb*	*Temp. Ft-lb*	*Temp. Ft-lb*
	62 30, 29, 28	72 38, 34, 30	76 32, 29, 28	80 26, 28, 29	72 20, 26, 25	72 34, 34, 36
	32 24, 24, 20	20 32, 29, 29	58 24, 23, 25	40 15, 22, 23	32 8, 10, 11	32 10, 28, 30
	20 23, 20, 13	−20 6, 22, 23	30 4, 17, 23	30 6, 6, 25	20 5, 4, 9	20 7, 12, 30
	0 8, 6, 6	−50 16, 2, 2	20 4, 6, 26	20 4, 6, 20	0 3, 6, 3	0 3, 5, 5
		−65 2, 3, 2		0 3, 3, 3		−20 3, 4
V-Notch	88 23, 23, 21	68 60, 59, 47	76 32, 19, 17	80 18, 22, 23	125 42, 43	72 31, 31, 38
	52 13, 10	32 28, 20, 24	56 15, 12, 13	54 10, 15	100 15, 23, 20	32 8, 10, 10
	40 9, 9, 12	20 18, 18, 18	40 6, 8, 9	40 4, 6, 8	60 8, 10, 12	20 4, 6, 8
	30 7, 8	10 15, 14, 14	30 6, 6, 7	30 5, 5, 6	40 6, 7, 6	0 4, 4, 5
	20 6, 6, 8	0 7, 10, 7	20 4, 6, 4	20 6, 7, 4	20 5, 3, 5	−20 2, 4
	10 4, 6	−25 4, 6, 7		0 4, 4	0 2, 3, 4	
	0 3, 3, 4					

The properties of these steels are summarized in Table 3, where Chemical Analysis, Physical Properties and Impact Properties of all are tabulated.

SOD Test Results

The comparative properties of all six are shown in Fig. 15 where results from the SOD tests are plotted. Several interesting observations can be made on the basis of these data.

1. Wide variations exist in the brittle breaking stress below the SOD transition temperature.
2. Wide variations exist in the SOD transition temperatures for these steels.
3. The susceptibility of any steel to brittle fracture depends upon both factors mentioned above.
4. One steel appears to have two transition temperatures, while another appears to have a gradually falling brittle breaking stress at lower temperatures.
5. No conclusions on relative merits of different types of steel can be reached on the basis of these few tests.

Correlation of SOD Results with Properties of Steels

It is fairly obvious that it would be impractical to test every plate used in oil tanks or any other major

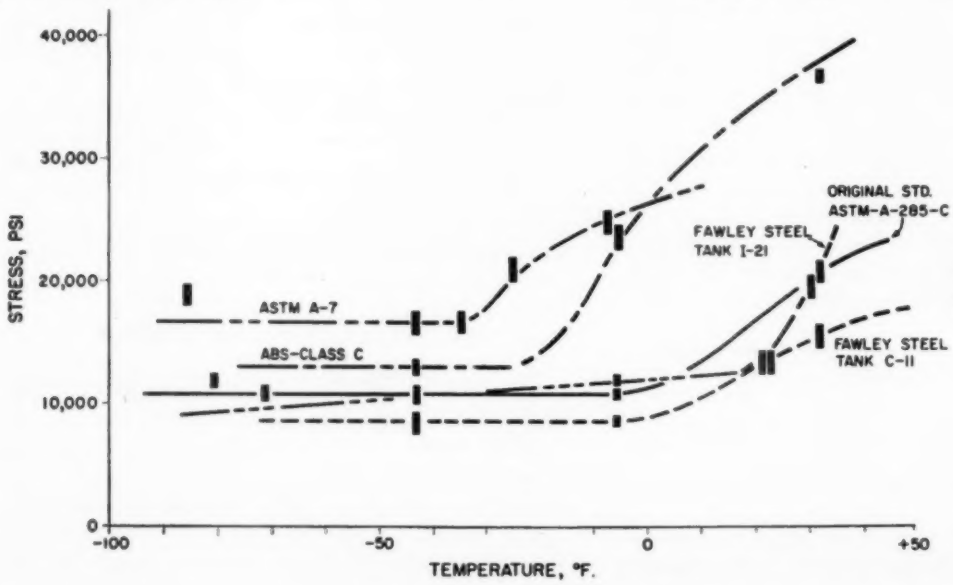


Fig. 15 Stress vs. temperature (Comparison of various steels tested in EED laboratory)

Table 4—Correlation of SOD Transition Temperature with Charpy V-Notch

Material	*5–6 ft-lb Charpy value, ° F*	*SOD brittle fracture test, ° F*
A—ASTM A-285	0–+10	0–+20
B—ABS Class C	−20–0	−20
Fawley Steel:		
C—1st Course C-11	0–+20	10
D—2nd Course C-11	0–+20	10
E—2nd Course I-21	+20–+40	30
F-ASTM A-7	−20–0	−30 – −20

structures by the SOD test to determine whether it would be safe from brittle fracture at proposed operating conditions. Throughout the investigation, therefore, an attempt has been made to correlate SOD test results with common physical properties as determined by simple conventional tests. After reviewing results from the steels tested, a fairly good correlation between the SOD transition temperature and Charpy V-notch impact results was found. This correlation is shown in Table 4. A Charpy V-notch value of 5–6 ft-lb corresponds to the point where the slope of the energy vs. temperature curve starts to increase markedly from the very low energy values. From the tabulation it can be seen that the temperatures are in fairly close agreement considering the spread in data possible from Charpy tests.

Much greater difficulty was experienced in finding some property which correlated with the brittle breaking stress plateau below the SOD transition temperature. Yield and ultimate strength seem to bear no relation, and impact energy values from Charpy tests do not seem related in any simple manner.

Very recently, an effort was made to relate the modulus of rupture in bending at liquid nitrogen temperature to the brittle breaking stress from the SOD test and the preliminary results of this work are shown in Table 5. This correlation shows promise but it is still too early to be certain that it is valid.

Table 5—Correlation of Brittle Breaking Stress Plateau with Modulus of Rupture in Bending (Liquid Nitrogen Temperature)

Material	*SOD brittle fracture stress plateau, psi*	*Modulus of rupture in bending, psi*
A—ASTM A-285	10,000–11,000	171,600; 179,500
E—Fawley Steel, Second Course Tank I-21	8,000– 9,000	160,000; 186,000
B—ABS Class C	12,000–13,000	222,000

VII. FUTURE WORK

The present program planned by the Standard Oil Development Co. will include: (1) Further tests to compare ASTM A-7 with ABS Class C. (2) An investigation of the brittle properties of thinner plates. (3) Additional work on size effect and impact effect, using a larger testing machine. (4) Further work on correlations between SOD test results and physical properties.

VIII. ACKNOWLEDGMENTS

The authors wish to acknowledge with gratefulness their indebtedness to their associates and the management of the Standard Oil Development Co. who made possible the rapid progress in these studies. The assistance of Professor Gensamer of Columbia University, who acted in a consulting capacity throughout the program, was invaluable. The tests themselves were capably run in the laboratory by R. A. Haisch and S. F. Herbster.

Discussion by M. Gensamer

It seems difficult to explain the results presented by Mr. Feely and his associates, just as it has been difficult to explain the earlier results of large plate tests in which the crack was initiated simply by increasing the tensile load until a crack started, by any adaptation of the Griffith concept. Such treatments have been advanced, first by Irwin,[1] then by Orowan[2] in a simple and elegant form based on Inglis' solution of the elastic problem of an internal notch, and recently by Wells[3] for an external notch by using the Neuber solution for such notches. It seems that while the Griffith criterion, that the energy consumed in advancing the crack be less than that released from the store of elastic strain energy, must almost surely be a necessary condition, it cannot be the only one.

In the Griffith-type calculations of Irwin and of Orowan, of the stress required to keep a crack moving, the stress varies as the square root of the reciprocal of the crack length. In these tests, as in the older ones, failure should occur then at any stress, however low, if a sufficiently long crack is provided. In these tests crack lengths were varied by a factor of more than four so that the stress should have varied by a factor of two; no such variation of stress with crack length was observed. In the older tests no complete failures were observed below the yield point, although the yield point was approached as a limiting value by very wide plates. In Wells' formulation, based on Nebuer's treatment of external notches, the stress should vary as the square root of the reciprocal of the net width of the plate. This solution predicts less variation with crack length but still too much, and again provides for no limiting, lower value of the necessary stress.

Wells derived the formula $\sigma = \sqrt{\pi ES/4a}$ for deep external notches and the formula $\sigma = \sqrt{3ES/2a}$ for shallow external notches, where σ is the stress, E is Young's modulus, S is the specific energy requirement per unit area of plate that is to be cracked and a is half the net width of the plate or the distance from the

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root of the crack to the centerline. Applying these to the data under discussion, and choosing 16-in. wide plates as the more favorable case, with crack lengths of $^3/_4$ and 2 in. so that 2 a has values of 14.5 and 12 in., the ratio of the stresses necessary by Wells' formulas should be 1.10. This is near the limit of error in any individual test, but should have been observed had the stress varied with crack length in this manner. For narrower plates the stress variation by the Griffith-Wells treatment should have been greater. The absence of any size effects in the data reported by Feely, *et al.*, for all tests below their transition temperature is inconsistent with any of the Griffith-type treatments.

Gensamer[4] treated the problem of the length of crack that would be developed in a plate of limited size, deriving the expression

$$x = \frac{lb}{2E} \cdot \frac{S^2 - So^2}{q}$$

where x is the crack length that develops, l is the effective plate length, b is the plate width, E is Young's modulus, S is the applied stress, So is a limiting stress level below which the crack cannot develop, and q is the specific energy requirement (q in this formula is the same as S in Wells' formula above, and the same as p in Orowan's formula presented at the same conference, for the infinite plate, $\sigma = \sqrt{Ep/b}$). In this formulation, the concept is introduced that some critical value of stress is required, below which the crack cannot propagate however much energy may be available.

Gensamer took l to be six times b, on the basis that cracks travel at about one-third the speed of sound, so that elastic strain energy stored at points more remote than three times the plate width was not available in time to be used. Giving q the same value as in a V-notch Charpy test at the 10 ft-lb level (1000 in-lb per sq in.), he calculated with good agreement the slope of a plot of the square of the stress causing failure against the reciprocal of the plate width, at temperatures just below the fracture-appearance transition temperature, for the wide plate tests conducted under the Ship Plate program. Such a plot extrapolates to the yield point for very wide plates. At such high temperatures fully developed plastic areas would be expected at the notch root, and an average stress higher than the yield point would be required to raise the stress at the root of the notch to the value required for fracture, even though the notch be quite sharp.

At lower temperatures, and with sharper notches such as real and running cracks, one would expect the critical stress to be less than the yield point, but not zero. There is some plastic action associated with the progression of a crack, even at temperatures below the transition temperatures reported by Feely, *et al.* Any plastic deformation at the root of an advancing crack decreases its effectiveness, by relaxing the stress at the crack root. Neuber[5] developed the formula

$$\frac{S}{p} = \frac{4}{\pi}\sqrt{\frac{a}{r}}$$

where S is the stress at the crack root, p is the average stress on the net section, a is the distance from the crack root to the centerline and r is the radius of the cylindrical zone at the advancing crack edge, in which the stress is relaxed by plastic deformation. It is just as though a hole of radius r had been drilled at the end of the crack, for no load is being carried there because of plastic yielding. This makes the effectiveness of the crack very much less than would be the case if the action were wholly elastic. It means that some stress is required to keep the crack going, to produce the plastic action that seems to be a necessary prelude to fracture. Gensamer has observed, but not yet published, that some deformation (about 2%) precedes fracture in well-polished tensile test specimens even at 25° K, just above the hydrogen boiling point.

It is interesting to calculate what might be the radius of the stress relaxed zone from the data of Feely, *et al.* They observed that unnotched, polished bend specimens failed at 79° K (boiling point of nitrogen) at stresses of the order of 200,000 psi. Such a value might be expected for the yield stress at the temperatures and high rates of straining prevailing in the plastic zone at the edge of an advancing crack. Their observed stress to keep a crack running, after presenting the stressed plate with a running crack, was of the order of 10,000 psi. This makes the stress concentration factor about 20. Putting this equal to S/p in Neuber's formula, a/r takes the value of 250. With a having a value of 6.25 in., as in their relatively deep notched 16-in. plates r is seen to be of the order of 0.025 in.; with narrower plates it would be proportionately less. This is not an unreasonable value, keeping in mind the roughness of the fracture surface and how the crack progresses by the nucleation and growth of new fractures in advance of the moving front, these joining up at different levels to produce the characteristic "chevron" markings.

It seems, though, considering the constancy of the fracture stress level in the work under discussion, both with changes in geometry and in temperature below their transition temperature, that Neuber's formula is not really applicable to such wide plates, and that the stress concentration factor is in fact constant when we are dealing with deep cracks in wide plates. The data suggest that this stress concentration factor might be about 20, and that further increase in the plate width would not cause any change in this value. By testing narrower plates, until a size effect set in, one might evaluate the effective radius at the root of a crack.

From a practical point of view, this limitation on the stress concentration factor is of very great interest, for it holds out the hope that we can design safely for even quite brittle materials, by keeping the average stress below a critical value. For something as brittle as glass, this critical stress would be quite low, for there is certainly little deformation at the advancing crack edge to limit the effectiveness of the crack as a stress raiser. But steel down to the temperatures used in

these tests does not seem to be glass brittle, and the stress concentration at the root of a running crack is limited. It would be extremely interesting to extend these tests to still lower temperatures to see if at some very low temperature higher stress concentrations and lower critical stresses might be obtained.

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Welding Research in the European Universities

(*Continued from page 98-s*)

European cities because the International Institute of Welding held its 1953 meeting in Copenhagen and will hold its 1954 meeting in Florence.) Whereas between Houston and Cleveland you fly over several states of a single country, the flight from Copenhagen to Florence is over four autonamous countries, not counting numerous others on all sides. Your States are bound together by a single language and common culture, but the individual countries in Europe each have their own history, language and culture. Furthermore, progress for each of them has been interrupted by wars which devastated much of our Continent. Because of these differences and interruptions, industrial development has usually followed widely divergent paths. Consequently, even for such a limited subject as "Welding Research in Universities," it is impossible to speak of a single organization in each country, much less of a central unit such as you have in your Welding Research Council.

In order to talk about development of research and to make comparisons between different countries, it is essential, first, to establish a basis for discussion.

Generally, in making comparisons, we are accustomed to basing these on some numerical criteria—for example, the sums allocated to research as a percentage of business turnover or in relation to some production figure. These proportions are sometimes used to indicate the degree to which a specific industry supports research. Such criteria might serve you well, but we in Europe are confronted with differences in purchasing power and wage rates expressed in various currencies in various countries.

In comparing laboratories, we find that first-class work with far-reaching results can be produced by an excellent staff on a very limited budget; and, conversely, a costly laboratory with the very latest of equipment is no assurance of effective results. Heavy capital investment in elaborate plant and equipment without efficient staff, sometimes merely creates a spectacular exhibition somewhat like a museum. A true comparison of research laboratories should be made on the same basis used in industry—that is, on the basis of output and value rather than on capital investment.

Unfortunately, however, the output of research laboratories cannot be measured by weight of product nor is there a criterion for quality because most of the results are directed toward the future and can only be evaluated at some later date. Of some help in determining the value of research might be published scientific treaties, especially if obtained results can be traced to them. They could also be helpful in estimating a quality coefficient for research personnel as well as for evaluating a given laboratory's output.

For these reasons it is easy to see why one must be wary of opinions expressed and judgments passed on the development of research. Due to the complexity of the problem, they are hardly ever well founded.

Lest you conclude from these preliminary remarks that there is no welding research worth mentioning in the European universities, I hasten to remind you that Mr. Jaeger, President of the International Institute of Welding, is Professor of Naval Construction at the University of Delft, Netherlands, and that a number of presidents and members of the International Institute of Welding technical committees are also university professors. I know that you correspond with many of these gentlemen and are familiar with their work.

However, as is also the case in the United States, we have very few professors of welding as such. This is easily explained. Welding is not quite yet a science nor a specific industrial subject. It is rather a technique used in a large number of industries. Chairs for professors of welding are rare, and, as suggested above, the structure and aims of universities vary from country to country. For example, research at some universities is directed to the study of general questions without immediate relation to industry—that is, research problems as determined by the professor himself as part of his own scientific activity rather than by industry. In such cases, specialized institutions of research are often set up and supported by particular industries. (Their work may parallel that of the university and be in collaboration with it.) At other universities, professors relate their work to problems of a particular industry which pays for such research work. These are only two of many examples I could give. However, in taking an

over-all view, we find that, for the most part, research work is carried out on existing problems through university professors and scientists and through professional research centers.

A big advance to welding research was the creation of the International Institute of Welding a few years ago. At last a common meeting ground was established. National welding groups, long having realized the limitations of working alone, could pool their efforts on an international level. This sharing, however, was at first somewhat restrained, but more and more frequently a willingness to exchange information on all phases of research and development has been evidenced. This community of effort which each desired, also brought about a spontaneous reorganization within the individual countries—for example, the creation of specialized committees in which all interested parties cooperate, including universities.

While it is indisputable that the International Institute of Welding has had a happy influence on the development of research in Europe, one must not conclude that it is only a European association. It is rather an entirely international body, and, as you know, the AMERICAN WELDING SOCIETY and the Welding Research Council are among its most prominent members.

Although it may appear that we in Europe are still working quite independently of you in the field of research despite the uniting efforts of the International Institute of Welding, it is not actually so. Admittedly, we continue to study problems which you have solved—thanks to the excellent organization which you have long had and also the ability of your university people. However, long experience in research has taught me that no problem is ever definitely solved and that each problem has various solutions from which we all can benefit. I would like to illustrate this point.

Like yourselves, we too have been interested in the weldability of carbon steels and their susceptibility to brittle fracture. Because of some unhappy experiences early in the study of this problem due to our different methods of manufacture which produced varying qualities of steel, we became aware of the importance of notched-bar impact tests. We tended to establish requirements which were too severe with respect to required performance, and, today, in many European countries we are trying to see to what extent these may be relaxed, at the same time staying within reasonable limits of safety. It would appear that with you the tendency is quite the reverse and that some of your experiences have led you to use the impact test to increase the stringency of your specifications without exceeding the safety limit.

Another example is afforded in the use of what we call "basic electrodes" and which you call "low hydrogen." We were using these even before the war, and consequently never learned much about the mechanism of "under-bead cracking" (we learned the expression from you). However, you were seriously confronted by this problem and had to study it, with the result that you analyzed the causes and then perfected the low-hydrogen electrodes to solve the problem.

Finally, leaving this subject solved more or less satisfactorily, this does not mean that it should not be reexamined on the basis of common experience and in the light of new facts. I could mention others which could still be of interest. For instance, residual stresses and their influence on the service behavior of welded constructions. I imagine on your as well as on our side, I would find defenders of numerous theories and contradictory ones at that!

Actually, I do not think that the division of Europe into independent nations, each with its own conception of teaching and research, especially with regard to welding, has been entirely disadvantageous. On the contrary, our work in the International Institute of Welding seems to have benefited from the diversity of intellectual training and, consequently, from different opinions on the method of attacking problems. We would not have had this advantage without these various backgrounds. I feel certain that if a larger number of your compatriots could participate in this work, they would find the spirit quite contagious and would greatly profit, carrying home useful results and helpful information to share with their co-workers in the United States.

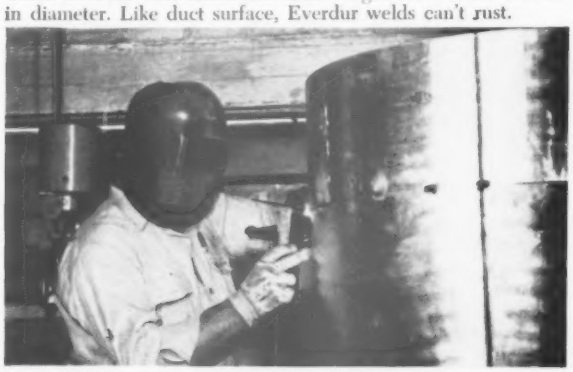
As mentioned at the beginning, I have tried to explain to you why I cannot discuss in detail the subject of welding research in our universities. I still have, however, the agreeable duty to suggest the means by which you may form more specific ideas than those which I have just given.

In May and June of last year you received a group of European technicians who came to see, in particular, how you organize your welding research. You showed them everything they wanted to see and explained much which surprised them. They returned extremely happy with all they had learned and also with much appreciation for all the kindnesses you extended to them. All of them told you in leaving of their desire to see you in Europe some day. May I hope that this is not in vain and that many of you will be able to visit our laboratories and our installations in Europe? That would be, believe me, the best method for welding the contacts already established on the technical and particularly the human level.

I know that this is talking of a project which many of our mutual friends are exploring. I would be personally extremely happy if it succeeded, the more so because that would be perhaps an opportunity for you to excuse me for the few minutes which I have just caused you to lose.

Everdur-welded, galvanized iron twin air risers supply heating-cooling air for Dallas' new Republic National Bank Building.

These Everdur-weld fabricated ducts ranged from 54 in. to 3 in. in diameter. Like duct surface, Everdur welds can't rust.



Seams were first tack-welded, then welded around the periphery, using ⅛-in. Everdur-1010 Rod and the carbon-arc method, on the 18-gage galvanized sheet metal ducts. The welding rod was supplied by Hill Equipment and Supply Company, Dallas, Texas.

View down one of the twin air risers, showing branches to each floor. Over a mile of Everdur welds were used in this system.

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